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THE PLANT DISEASE REPORTER

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THE PLANT DISEASE SURVEY

Supplement
190-198
1950

Division of Mycology and Disease Survey
BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING
AGRICULTURAL RESEARCH ADMINISTRATION
UNITED STATES DEPARTMENT OF AGRICULTURE

SUPPLEMENT 190

PLANT DISEASE FORECASTING: A SYMPOSIUM

Supplement 190 January 30, 1950

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

PLANT DISEASE REPORTER SUPPLEMENT

Issued by

THE PLANT DISEASE SURVEY
DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station Beltsville, Maryland

PLANT DISEASE FORECASTING: A SYMPOSIUM

Plant Disease Reporter
Supplement 190 January 30, 1950

The following five invitational papers were presented in New York City December 28, 1949, at a symposium on the general subject of "Plant Disease Forecasting." This symposium was held in connection with the program of the American Phytopathological Society meeting with the American Association for the Advancement of Science, and was sponsored by the Plant Disease Survey under the chairmanship of Paul R. Miller.

The program was dedicated to the memory of Dr. Neil E. Stevens, who pioneered in forecasting plant diseases, a subject dear to his heart and one he deemed of vital importance.

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EARLY STEPS IN PLANT DISEASE FORECASTING IN THE UNITED STATES[1]

Russell B. Stevens

As is well-known to each of you, the story of the creation of the world is told in Genesis in 300 words. It should then, be easy to describe in ten minutes the early steps in plant disease forecasting in the United States. Such was the assignment.

Even in so condensed a summary, it seems wise to define at least one term. By "forecast", as used here, I think we all understand an estimate of the probable loss from a plant disease made sufficiently far in advance of onset that growers may alter their management methods accordingly. Not included are reports on the status of a pathogen such as are useful in timing spray applications.

Disease forecasts are inherent in the management of many crops and thus must be old in agriculture. A man who places an order for a spray rig and for spray materials is motivated by an unexpressed forecast that disease incidence will justify their use. The legislature of Connecticut in 1726 (1) passed a law providing for the eradication of barberries. Though a bit equivocal in the matter, this body was motivated by a forecast of the severity of stem rust of wheat. In this case then, as in so many others, agricultural practice was centuries ahead of so-called agricultural science.

The entomologists ventured into the field of forecasting much earlier than the plant pathologists. I have not looked up the records, but they certainly were active before 1912, and they still are.

To the best of our knowledge, the first formal forecast of plant disease, for the benefit of growers as a group, was published in the Wareham (Mass.) Courier in September 1923. This was Stevens' (N.E.) forecast of the probable keeping quality of the cranberry crop of Plymouth County for that year. The purpose was to guide growers in the handling and marketing of that crop. The forecast was based chiefly on temperatures of the two months before the cranberry comes into bloom: that is, May and June. The weather, especially rainfall, for July and August, months during which the fruit was growing, was also considered. A complete review of this work can be found in Massachusetts Agricultural Experiment Station Bulletin #402. Forecasts were continued until the fall of 1935. During this 15-year period all forecasts proved correct except that for one of the two major varieties in 1926.

Dr. Stevens' friend and co-worker of many years, Dr. H. J. Franklin, has now taken up the more difficult and, in some ways, more interesting problem of making forecasts in the middle of June which can be used by growers in deciding whether or not it would be practicable to spray for control of fruit rots. The chief use which could be made of the earlier forecasts was in handling the harvested crop. It may as well be noted that from the very first year they were considered in naming the opening price.

In any outline of the history of plant disease forecasting in the United States the work on curly-top of sugar beet in southern Idaho should certainly be included. This work, begun by Walter Carter in 1927, has been continued by various workers in the Bureau of Entomology's field laboratory at Twin Falls, Idaho, since that time.

If questioned, the entomologists would likely insist that they are not forecasting the incidence of curly-top, but only reporting on the condition of the beet leafhopper. It is, however, generally recognized that the beet leafhopper rarely becomes sufficiently abundant to cause great damage by its feeding. The virus of which this insect is vector is destructive, under favorable conditions, even to improved curly-top-resistant varieties of sugar beets (2). It is also well known that beets are subject to the maximum degree of curly-top injury when they are attacked by the beet leafhopper while the plants are in the seedling stage. If the peak of leafhopper movement coincides with the seedling stage of the susceptible crop, a greater loss will result than would otherwise be the case. It would appear then that these forecasts are of interest primarily because of their relations with the curly-top disease and the possibility of avoiding it by changing the planting date. It would also appear that they are of great interest to us in connection with the forecasting of plant disease as a means of avoiding disease losses. As given to us in a recent letter from Dr. J. R. Douglass, entomologist at Twin Falls, who is now carrying on this work, statements of beet leafhopper conditions are based on:

1. Beet leafhopper populations in the summer-breeding areas during the fall.

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[1] This paper was in large part prepared by the late Neil E. Stevens, of the University of Illinois, who died June 26, 1949.

2. Fall germination of wild host plants.
3. Winter weather conditions.
4. Survival of host plants and leafhoppers during the winter.
5. Magnitude of the overwintering female populations in the spring.
6. Distribution, abundance, and suitability of the spring host plants.
7. Spring weather conditions.
8. Percentage of leafhoppers carrying the virus of curly-top.

With information on these points in hand the grower might be able to reduce his loss from curly-top either by adjusting his planting date or in extreme cases by reducing his acreage.

The experiment in forecasting occurrence of Stewart's disease (bacterial wilt) of sweet corn is described in two papers published in the Plant Disease Reporter. The first (3), summarizes the historical evidence and advances the hypothesis that incidence of bacterial wilt could be predicted on the basis of winter temperatures. The second paper (4) is a summary by Haenseler and Stevens in which results were tabulated and it was pointed out that the suggested method did indeed enable one to foretell within a very few miles the northern limits of commercial incidence of the disease. By the year 1940 many had lost interest in the project. It had proven too easy. Also, of course, it had its origin in a very immediate problem, that of trying to determine in the spring of any given year whether it was safe to plant early maturing but wilt susceptible varieties of sweet corn in Rock County and Long Island, New York, or whether it would be better to plant later-maturing, more resistant varieties.

By 1940 varieties which it was hoped would combine early maturity with resistance to this disease were becoming available. A recent re-survey of conditions in the northeastern United States covering the years 1945 to 1948 shows, however, that the relation indicated in the earlier papers still holds. Moreover, there is at least a fair chance that Mr. Boewe, of the Illinois Natural History Survey, will be able to develop a method of forecasting the late infection stage of bacterial wilt, at least in the State of Illinois.

It may as well be admitted that in this case, even more than that of the earlier forecasts, the very simplicity of the suggested methods tended to cast doubt upon them in certain circles (circles which fortunately did not include the pathologists of Connecticut, New York, or New Jersey). The suggestion that with no information other than that furnished free by the United States Weather Bureau, no equipment beyond paper and pencil, and no mathematics higher than simple addition in three digits, a county agent could tell what varieties of sweet corn could safely be planted in this area naturally seemed archaic in an equipment-minded, statistics-minded age.

The one great advantage, certainly, was the written records of disease loss estimates made by competent observers. In regard to cranberries the records were those kept by Henry Griffith, chairman of the board of inspectors of the New England Cranberry Sales Company. For sweet corn there were records by Stewart, Clinton, Rand, Cash, and others. Moreover, the work related to an area in which the records of the U. S. Weather Bureau have been kept in a relatively large number of places and over a relatively long period of time. Imperfect as weather records are and much as they have been critized by workers in agriculture, they are our only records comparable to one another and maintained on the same basis over a considerable length of time. It is hard to see, therefore, how any forecasts based otherwise can be of any immediate or wide application.

Finally, we may as well recognize that forecasting, if anybody takes it seriously, involves a considerable degree of risk. We are here trying to do exactly what is described in an aphorism usually attributed to Samuel Butler the younger, "Life is the art of drawing sufficient conclusions from insufficient premises."

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UNIVERSITY OF TENNESSEE

VALIDITY AND VALUE OF PLANT DISEASE FORECASTING[1]

K. Starr Chester[2]

Science is concerned with the causation of natural events. When the principles of causation are discovered, science reaches its goal and it becomes possible to predict that certain natural events will necessarily follow given circumstances. The chemist tells us that if we will add sulfuric acid to naphthalene at 40° C., a 96 percent yield of alpha-monosulfonate will be produced, but that if we make the addition at 160° C. we will obtain an 85 percent yield of quite a different beta compound. Does this differ essentially from the case in which the plant pathologist tells us that if we add the blight fungus to a potato field at a temperature below 75° F. in the presence of more than 75 percent relative humidity, we will obtain an outbreak of blight? Both the chemist and the pathologist are using a conventional and acceptable method of science, -- forecasting.

An editorial in a leading newspaper in 1946 read:

"Famine conditions in Europe and Asia have been aggravated sorely by a disastrous crop failure in the southern hemisphere. Not until December came could the world's planners possibly know that the transequatorial fields had failed to yield their expected harvests, and by then it was extremely late for the planners to design a new program of famine prevention."

This editorial (from "The Daily Oklahoman", April 29, 1946) strikingly illustrates the important service that can be rendered agriculture and society by developing the ability to forecast crop prospects reliably and predict crop losses or the escape of crops from loss factors. The crop hazards that vary from one season to another, the uncertain factors for which forecasts might be most useful, are weather, insect pests, and crop diseases. Progress toward the more accurate and more timely forecasting of losses or escape from any and all of these hazards is progress toward sounder agricultural economy, whether viewed from the standpoint of the farmer, individually or collectively, the handlers of agricultural commodities, or national security.

The value of reliable agricultural hazard forecasts has many forms. If an outbreak of insects or disease is foreseen, the timely warning may permit combatting the pest with chemicals to avert the losses that would otherwise surely follow from attacks of such troubles as grasshoppers, boll weevil, potato and tomato blight, and tobacco blue mold. If the forecast is for freedom from attack, farmers can save the expense of spraying needlessly.

But even when the predicted outbreak cannot be fought directly with chemicals, reliable forecasts can also be useful. Take the case of the southwestern wheat grower whose stand of wheat is only fair, because of fall drought or winter killing. He is undecided whether to allow the crop to mature or to pasture it off or to cut it for hay and plant the land with a substitute crop of corn, sorghum, field legumes, or cotton. His neighbor is undecided whether this is likely to be a season of abundant yields, warranting purchase of a combine for custom harvesting. Another neighbor is wondering whether the coming crop will justify the expense of building more storage facilities, and the local grain-elevator operator has similar problems. The local railroad agent is undecided how much rolling stock should be made ready for the harvest, and the banker would like to know how much credit he can allow on the security of the new crop.

To all of these men, reliable forecasts of crop yields or yield factors are valuable aids, contributing toward a sounder agricultural economy. Plant disease is only one yield factor. By itself, it does not necessarily spell crop success or failure, even though its effects are commonly late in the season. It would be folly to attempt to predict yields from a knowledge of this factor alone. Yet it is a weighty factor which, combined with insect pests and long-range weather forecasts, can be of great service to agriculture and the industries dependent on agriculture.

While reliable crop-pest forecasts are of value to the farmer, the processor, the marketer, the manufacturer and distributor of pesticides, and all of the others who are concerned directly or indirectly with harvest returns, from a national point of view such forecasts have even greater importance. The economics of this nation, and of those other nations that must rely on this one for agricultural products, are dependent on our production levels. If these levels are threatened by disease or any other hazard, the sooner this can be foreseen, the greater the opportunity will be for averting the losses by crop protection or compensating for them by substitute production or conservation. In this light, the forecasting of crop hazards is a national resource.

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[1] Presented at the Annual Meeting of the American Phytopathological Society, New York, December 28, 1949.

[2] Supervisor, Agricultural Division, Battelle Memorial Institute, Columbus, Ohio.

Reliable pest forecasting is not intuition or guesswork. It is scientifically sound reasoning based on painstaking study of the habits of crop pests and the way these are influenced by weather, soil, and cropping practices. Plant pests do not suddenly break out without warning. They must have a period of preparation, of weeks, months, or even years, when the pest population is slowly and steadily increasing. The epidemic is merely the final step in a long chain reaction. If the early steps in this chain reaction are well known, together with an understanding of the influences of weather, the final step, the epidemic, can be predicted with some degree of accuracy. Each year agricultural research is revealing more of the secrets of the life and reproduction of crop pests, providing more of the basic information that makes reliable pest forecasting possible.

The forecasting of plant disease epidemics is rapidly growing in importance and will continue to do so with the growth of understanding of disease-weather relationships and use of the long-range weather forecasting which has been an outstanding scientific accomplishment during the recent war. If disease forecasting could be combined with accurate estimates of probable losses, these might often be averted with substantial benefit to grower and consumer.

In only one branch of plant pathology has the determination of present and future disease loss become well developed. This is in forest pathology, where accurate estimation of wood decay volume has gained leading importance in determining optimal cutting cycles and in appraisal of present and potential sales value of the crop.

The outcome of a horse race is determined not so much by the position of the horses at any given moment as by the speed at which they are running. So, too, with plant diseases; a single inspection of disease may give very little indication of the dynamics of disease development. Just as an experienced seaman can determine the course and speed of a distant ship by signs that are meaningless to the landlubber, so the phytopathologist can learn to recognize the evidences that a plant disease is accelerating, static, or decelerating in intensity. It is important that we give attention to the dynamics or tempo of disease development, since this increases our ability to foresee future loss, sometimes early enough to permit the intervention of loss-preventive measures. Where disease tempo depends on unpredictable future conditions, a knowledge of this fact brings out the limitations of reliable forecasting.

Some diseases progress at a fairly regular rate that is relatively insensitive to normal weather fluctuations. In such cases the tempo is expressed by the regression of disease intensity on time, and the forecast of disease intensity at any given time in the future can be read directly from the regression line. The table of losses from wheat stem rust of Kirby and Archer is based on the assumption that rust intensity increases with time at a regular rate, and, to the extent that this assumption is correct, it permits forecasting both future rust intensity and ultimate loss. Similarly, the linear regression of loss on symptom expression with sugar beet yellows can be used in forecasting yields and enabling beet factory operators to make appropriate provision for receiving the crop.

In America, current interest in plant disease forecasting centers in the warning service of the U. S. Plant Disease Survey, an outgrowth of the potato and tomato late blight forecasting developed during World War II. It does not appear to be commonly known in America that forecasting or warning services for potato late blight and downy mildew of grape were initiated in Europe a quarter-century ago and became highly developed during the 1930's.

In France and Italy, the vine mildew warning service developed in parallel fashion, with networks of observation stations and wide publicity of warnings of imminent mildew attacks. In France, before the availability of the telephone, grape mildew warnings were flashed from village to village by the heliograph or sound signals and the French telegraph service forwarded coded warning telegrams to the thousands of subscribing vineyardists at a special low rate. This permitted substantial savings in spray costs, the crops being protected only when the protection was needed. Reliability of the forecasting was secured by maintaining disease observatories and working out the necessary relationship between weather and disease outbreaks.

The French vine mildew forecasting and warning service, which proved to be generally accurate and which resulted in important savings of crops and spray expense, was based on extensive studies of the interrelation between weather, fungus, and disease.

The French workers have made interesting use of phenology in connection with spray warnings. Finding that the first attack of sycamore by the anthracnose fungus, Gnomonia veneta, regularly precedes the first attack of the vine mildew by several days, the sycamore disease is used as an index of imminent vine disease.

In Germany, vine spray warnings have been based on K. Müller's "incubation calendar", which was developed in 1913 and which is claimed to have averted immense losses and more than doubled grape yields in the Baden area over a 19-year period.

In Russia, Müller's "incubation calendar" has been found useful if adapted to local conditions, and vine mildew forecasting is considered feasible on this basis.

Forecasting and spray warning services for potato late blight evolved independently in Holland, England, France, and the United States. Holland led the way when, in 1926, van Everdingen proposed his four rules governing the appearance of late blight. Development of the disease, according to the Dutch rules, required (1) a night temperature below the dew point for at least 4 hours, (2) a minimum temperature of 10° C. or above, (3) mean cloudiness the next day of 0.8 or more, and (4) at least 0.1 mm. of rain during the next 24 hours. Provision for control measures was recommended only after days fulfilling all four of these conditions.

Answers to questionnaires sent out by the Dutch Phytopathological Service in 1926 confirmed the reliability of the Dutch rules, and arrangements were made for the Royal Dutch Meteorological Institute at Te Bilt and its observatories in the potato-growing sections to issue blight warnings that were broadcast with the weather reports and issued through the press. Between 1929 and 1933 the Dutch rules for late blight forecasting were tested in England and found to be generally satisfactory, though with occasional irregularity. These rules, somewhat modified, worked well in Devon and Cornwall but were later simplified to two rules: (1) minimum temperature lower than 50° F. and (2) relative humidity greater than 75% for two or more days. These two rules provided the best of the several forecasting methods tried, and were used thereafter in the British warning program.

During the past decade the writer and his associates in Oklahoma have developed a basis for forecasting the severity of wheat leaf rust and have used it successfully in rust forecasting for nine years. Two of the forecasts were of serious epiphytotics (1938, 1945), two were of abnormally light rust development (1944, 1948), and the others (1939, 1941, 1946, 1947, 1949) were of no more than normal rust injury. In all cases the outcome in Oklahoma was as anticipated, and usually the condition of rust which was forecast for Oklahoma had its counterpart throughout much or all of the wheat areas to the north. Issued usually on April 1 of each year, the forecasts have aided farmers and grain-elevator operators in planning for harvest and disposal of the crop, and in some cases they have been decisive in determining whether to allow crops of borderline condition to go to maturity or, alternatively, to abandon the wheat in favor of spring-planted summer crops.

Since 1942 the forecasts have been based on an intensive analysis of the overwintering and early spring renewal of rust, correlated with late winter and early spring weather conditions, and an extensive survey the last week of March to determine whether the findings of the intensive study have statewide application. The basis of forecasting lies in the facts: (1) that in Oklahoma the weather from April 1 onward rarely if ever is a factor limiting rust development, (2) that the principal source of rust in this area is inoculum from overwintered local infections, (3) that the weather of December, January, February, and especially March is critical in determining spring renewal of the rust, and (4) that the level of rust intensity on April 1 is the principal factor determining its destructiveness from April till harvest in June, since the number of possible generations of rust increase is limited by time, even though the environment is constantly favorable, and the initial intensity of the rust April 1, the other factors being constantly favorable, will determine the final outcome of the disease.

The 1949 forecast was for no more than normal or average rust development. Some damage was expected in late-maturing fields and in low, wet locations, but the bulk of the crop was expected to rust late. This was borne out in Oklahoma. Although May-July rainfall in Oklahoma was 136 percent of normal, excessive rust damage was localized, principally in late-maturing fields. In Kansas and Nebraska, with May-July rainfall of 141 and 122 percent of normal respectively, wheat yields were disappointing. While leaf rust was only one of several factors responsible, the rust was evidently more destructive than in an average year, though not reaching the proportions of the epiphytotics of 1938 and 1945.

Plant Pathologists are unduly timid about disease forecasting, as though a single erroneous forecast would be ruinous to their reputation. The official weather forecasts have an accuracy of about 80 percent, yet no one questions their utility. A comparable margin of error is acknowledged in the "predictions of things to come" by leading news commentators, agricultural and industrial publications, economists, and those who conduct public opinion polls. Yet, these predictions are eagerly received and often put to good use. No one expects the forecaster of weather, news, prices, or plant diseases to be infallible; if his forecasts are correct four times out of five, they are of proven value and far preferable to no forecasts at all.

The latent plant disease forecaster may be inhibited for other reasons than fear of the consequences of an occasional error. Many plant pathologists who are in positions to forecast plant disease are in tax-supported organizations, and they may be restrained from forecasting lest it direct the taxpayer's attention to the temptation for public officials to take private advantage of their foreknowledge of crop prospects. In other cases, they may be deterred from making low-hazard forecasts by fear of criticism from poorly informed agriculturists, who regard such forecasts as harmful because of their possible effect in reducing farm crop prices. But, these objections to forecasting are economically unsound; they avoid a lesser, real or imaginary evil by accomplishing a greater one, -- depriving the men of the agricultural industry of information that would contribute toward more profitable and economic production and marketing.

It should be clear from the examples recounted tonight and others in the literature, that the prediction of plant disease outbreaks and losses is not guesswork. It is a useful application of the study of plant disease appraisal and epiphytology, with a record of reliability that compares very favorably with the admittedly justifiable forecasting of weather, crop yields, and other natural occurrences. It is equally clear that plant scientists have made only a bare beginning in developing this phase of their research, and that a great field of service to agriculture lies before us, awaiting cultivation.

BATTELLE MEMORIAL INSTITUTE

THREE YEARS' EXPERIENCE FORECASTING LATE BLIGHT IN TIDEWATER VIRGINIA

T. J. Nugent

In 1946 late blight caused severe damage to the potato and tomato crops in Eastern Virginia, as well as in many other sections of the United States and Canada. This was the first occurrence of such an epiphytotic in Eastern Virginia since 1938, and caused Dr. H. T. Cook, at that time Plant Pathologist at the Virginia Truck Experiment Station, to begin a study of weather conditions of the past several seasons in hopes of formulating a method of forecasting that would give the growers ample warning when such outbreaks were likely to occur. The results of this study are reported by Cook (1).

In brief, Cook found that the critical period for blight development in Eastern Virginia began May 8. Starting with this date he charted the average cumulative rainfall for the blight and non-blight years from 1930 through 1946 and constructed a strait median line between the lines for the blight and non-blight years. This line was designated as the critical rainfall line. The critical temperature above which blight would not be important was considered to be 75° F. When the cumulative rainfall line was above the critical rainfall line and the 7-day average mean temperatures were below 75° F. conditions were considered favorable for blight development. At least two consecutive weeks of favorable weather was considered necessary for a serious outbreak of blight to develop.

Checking back for a period of 31 years, Cook found that this method of forecasting would have indicated the years when blight caused damage. Blight did not cause damage in any of the years designated as unfavorable for blight development by the forecasting method. The only discrepancy was that in five of the seven years when weather conditions were favorable at the beginning of the critical period, they became unfavorable before serious damage from blight occurred. Since the forecasts would have made it possible to dispense with spraying or dusting for late blight control three out of four years, forecasting was considered economically worthwhile.

The real test of any method is its actual use. Forecasts were made by this method in Eastern Virginia by Cook in 1947 and by the writer in 1948 and 1949. A discussion of the results are presented in this paper. The forecasts during these three years were based on the daily weather reports from the United States Weather Bureau at Norfolk, Virginia. Use was made of their 5-day weather predictions. The daily weather reports from Onley, Virginia also were plotted for comparison with the weather conditions at Norfolk, Virginia. Forecasts were made at 7-to-10-day intervals during the critical period and were broadcast over the radio, published in newspapers, and sent in letter form to county agents and others who were interested.

THE 1946 SEASON

As stated earlier, late blight was very severe in 1946. The cumulative rainfall and 7-day average mean temperatures were plotted on a chart (Figure 1) to show the general relationship of these two conditions with the critical rainfall and critical temperature lines. As is shown on this chart in Figure 1, the cumulative rainfall lines in 1946 for both Norfolk and Onley were above the critical rainfall line by the end of the first week of the forecasting period and remained above this line for the entire period. At Norfolk the 7-day average mean temperatures reached 75° F. on June 12, but did not remain at 75° F. or above until June 22. At Onley the 7-day average mean temperatures did not get to 75° F. or above (except for 2-and 3-day periods) until July 9. If the forecasting method had been in use in 1946 the first forecast would have been made around May 15 and that year blight was first noted about one week later on May 23.

RESULTS OF FORECASTING IN 1947

The chart by which the 1947 forecasts were made is shown in Figure 2. The first forecast was issued on May 15, one week after the start of the critical period. There was no rain during the first week, and by the time of the first forecast at least 1.2 inches would have been necessary to bring the cumulative rainfall up to the critical rainfall line. Only one-half inch of rain was forecast for the next few days. Consequently Cook made the following statements in his first forecast on May 15. "Weather conditions during the week beginning May 8 have not been favorable for the late blight disease of the potato and tomato crops. The five day forecast issued by the local Weather Bureau on May 13 indicated that only about one-half inch of rain is expected between that date and May 18. Unless heavy rains occur it is unlikely that late blight will be important in the spring and summer potato and tomato crops in 1947. Therefore it probably will not be necessary to spray or dust to control this disease. Further notice will be given if the future weather conditions become favorable for blight."

Only 0.6 of an inch of rain had fallen between May 8 and 22 and the rainfall line on the latter date was 1.7 inches below the critical rainfall line. On that date Cook stated, in part, in his forecast that, "The weather continues unfavorable for late blight disease to develop on potatoes and tomatoes. Under the present weather conditions it is not necessary to spray or dust potatoes or tomatoes for late blight control." By May 29 only about one inch of rain had fallen during the first three weeks of the critical period. This was about 2.5 inches below the critical rainfall line. At this time Cook reported in his third forecast, "Weather conditions are still unfavorable for the late blight disease to develop on potatoes and tomatoes. ... Since the weather has been unfavorable for late blight during the first three weeks of the critical period, it is unlikely that the disease will be important during the summer of 1947."

During the following week only .16 of an inch of rain fell. Conditions remained unfavorable and Cook so reported on June 5 in his fourth and final forecast for that year.

Only a trace of blight was observed on potatoes during 1947 and this occurred during the latter part of June after abnormally low temperatures had prevailed and over an inch of rain had fallen. Furthermore, the few fields in which blight occurred were located in low areas and bordered by woods which tended to make conditions more favorable than conditions in general. Blight also occurred on tomatoes on the Eastern Shore in an area a few miles wide late in July. These outbreaks were quickly checked by a return of normal temperatures. Weather conditions favoring such late outbreaks rarely occur in Eastern Virginia and when they do they are of short duration.

RESULTS OF FORECASTING IN 1948

In 1948 the cumulative rainfall line for Norfolk area was quite similar to the cumulative rainfall in 1946 but at Onley rainfall was somewhat deficient and at no time above the critical rainfall line. The cumulative rainfall and 7-day average mean temperatures for these two areas are shown in Figure 3. The forecasts, or warnings in 1948, were based on the Norfolk weather. Soon after the forecasting chart was started that year conditions became favorable for blight to become established. By May 13 the cumulative rainfall was above the critical rainfall line and it was considerably above by May 17. The 7-day average mean temperatures were quite favorable, ranging between 64° and 73° F. Since the local Weather Bureau was forecasting more rain for the next few days the writer issued late blight warnings by radio, newspapers and letters to tomato and potato growers on May 17. In this first forecast it was stated that "Weather conditions during the past week have been favorable in this area for late blight of potatoes and tomatoes, and there are some indications that favorable conditions will prevail for the next few days. Dusting or spraying is recommended for control and should be continued until either hot or dry weather or both eliminates the threat of blight."

During the following week (May 18 to May 25) the 7-day average mean temperatures remained favorable (66° to 71° F.) but no rain fell. Late blight began to make its appearance around May 22 to 24 but was confined chiefly to those fields in which air drainage was poor. On May 26 the second late blight forecast was issued and the growers were advised about the weather conditions and warned that late blight had become established on potatoes in scattered sections throughout the area. They were advised that a continuation of the spraying and dusting program was recommended for those fields in which blight had become established and for the entire area if a rainy period started during the coming week.

Soon after this warning was released it began to rain and approximately four inches fell between May 26 and June 1. Mean temperatures continued favorable. On June 1 the growers were warned "that weather conditions as of this date have become quite favorable again for late blight to develop. Indications are that they will continue this week. Although blight has not become serious as yet there is enough disease present in this area to produce a widespread outbreak should present weather conditions continue for some time. Control measures are to be continued."

Weather conditions were still favorable on June 9. By this time blight had become quite serious in some fields in which no fungicide had been applied, not applied in time, or not applied often enough to give adequate protection but was not important in those that had been treated as directed in the forecasts. Inadequate control measures were due partly to field conditions unsuitable for ground applications. In the final late blight warning release on June 9 the writer

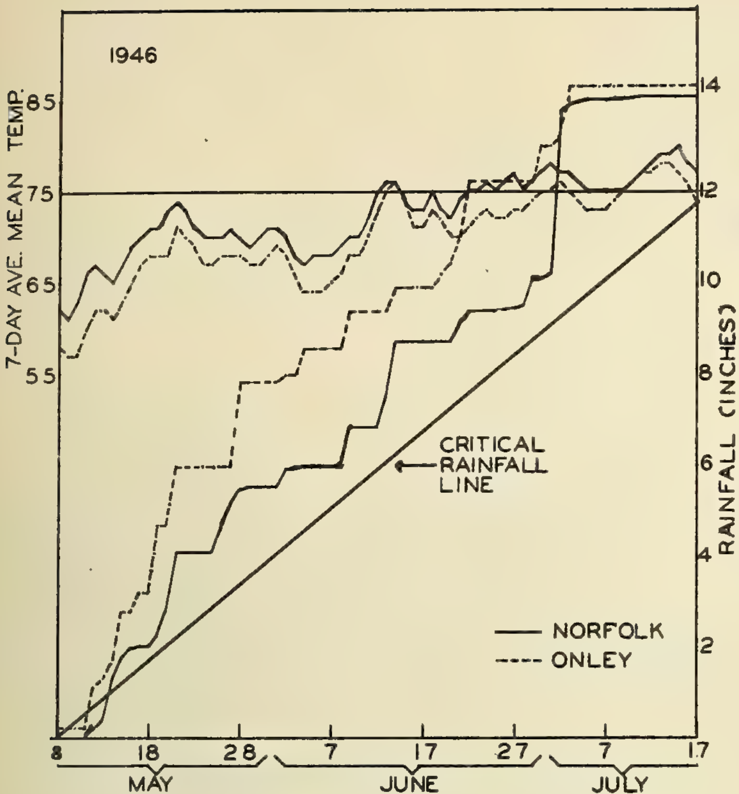

FIGURE 1—FORECASTING CHART FOR 1946

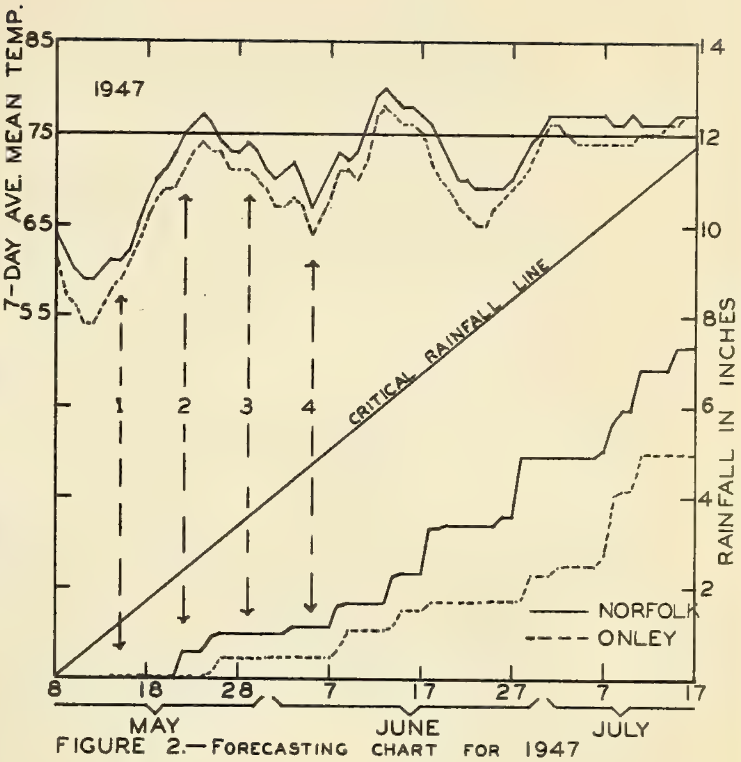

FIGURE 2.—FORECASTING CHART FOR 1947

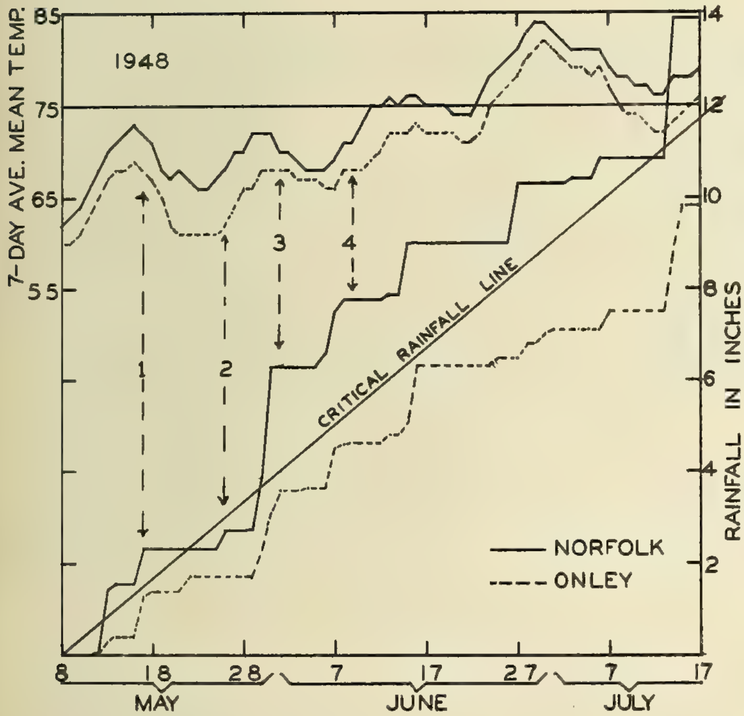

FIGURE 3.—FORECASTING CHART FOR 1948

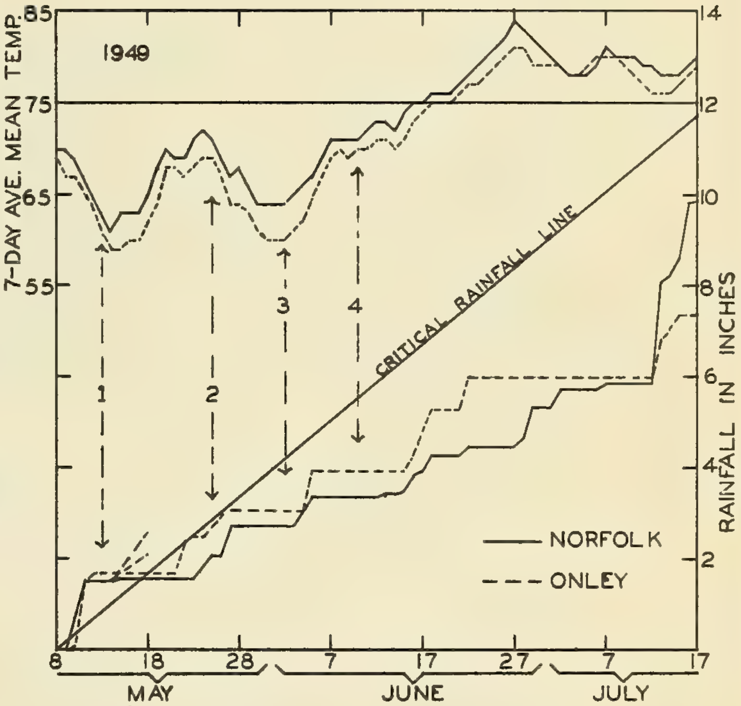

FIGURE 4.—FORECASTING CHART FOR 1949

stated that with the prevailing moisture supply the one weather factor that could check blight development would be mean temperatures above 75° F. By June 11 the 7-day average mean temperature in the Norfolk area did reach the 75° F. line and fluctuated within a degree above or below this line until June 24 after which the average mean temperatures were considerably above the critical temperature. These temperatures checked the blight enough to prevent a serious general epiphytotic such as occurred in 1946.

Although blight was quite serious in the Norfolk area and on the tip of the Eastern Shore peninsula in 1948 it never became a problem in the northern part of Northampton County or in Accomac County of the Eastern Shore area of Virginia. In Figure 3 it is shown that the 7-day average mean temperature at Onley, Virginia ranged 1 to 5° F. below those of Norfolk but the cumulative rainfall line was never above the critical rainfall line. The rainfall in the Norfolk area was above the critical rainfall line for practically the entire period.

RESULTS OF FORECASTING IN 1949

In 1949 we had a year that started out very much like the two blight years of 1946 and 1948 but ended up like the year 1947 when blight was not important.

Soon after the forecasting period started in 1949 there was a total of 1.56 inches of rain in Norfolk and 1.69 inches in the Onley area (Figure 4). This brought the cumulative rainfall line above the critical rainfall line. The five day weather prediction from the Norfolk Weather Bureau was for one-half to one inch of rain for the next few days. The growers were warned on May 13 that conditions were favorable for blight and possibly would continue so for the next few days. Since this would give blight a chance to get started, spraying or dusting of potatoes and tomatoes was recommended as a precautionary measure. The growers were told that the weather from then on, plus the adequacy of control measures, would determine the severity of the disease.

Late blight was found in the Cape Charles area soon after this warning was released but was confined to those fields with poor air drainage and bordered by woods. No rain fell during the week of May 15-21 and very little spread of blight occurred from these centers of infection.

Growers were warned on May 25 to continue the dusting or spraying in fields where air drainage was poor and to continue control measures for the entire area if cool rainy conditions should develop.

During the week of May 26-June 2 rainfall in general was quite deficient. and drying winds were prevalent. Mean temperatures ranging between 60° and 72° F. plus local showers resulted in some blight showing up at different locations but in general blight made little progress. The growers were advised that until a general rainy period prevailed the threat of damage from blight was not serious.

Rainfall was deficient by June 10 even though on the 4th and 5th of June 0.60 of an inch of rain fell at Norfolk and 0.88 of an inch of rain fell in the Onley area. High temperatures and drying winds followed soon after these rains. The five day weather forecast for June 11 to 15 was for temperatures slightly above normal and no rain. For these reasons the growers were advised in the fourth and final forecast on June 10 that indications were that late blight would not be a serious threat to potatoes in this area in 1949. They were warned, however, that since blight had become established in certain fields a prolonged cool rainy period could result in an outbreak which although not materially affecting the yield, could result in considerable tuber infection at harvest. They were advised that if such conditions should develop spraying or dusting would be good insurance.

The 7-day average mean temperatures reached 75° F. by the 16th to 18th of June and remained above the critical temperature line thereafter. In general blight was not a factor on the potato and tomato crop in 1949. It did cause some concern early in the season and caused some damage in a few fields where rainfall was supplemented with overhead irrigation.

COMPARISON OF THE 1946, 1947, 1948 and 1949 SEASONS AT NORFOLK

The blight forecasting method developed in 1946 was used in the spring of 1947, 1948 and 1949. A comparison of the cumulative rainfall lines for Norfolk for these years and for the severe blight year of 1946 is shown in Figure 5.

In 1946 the cumulative rainfall line went above the critical rainfall line early in the season and remained above for the entire forecasting period. Blight was very severe in 1946.

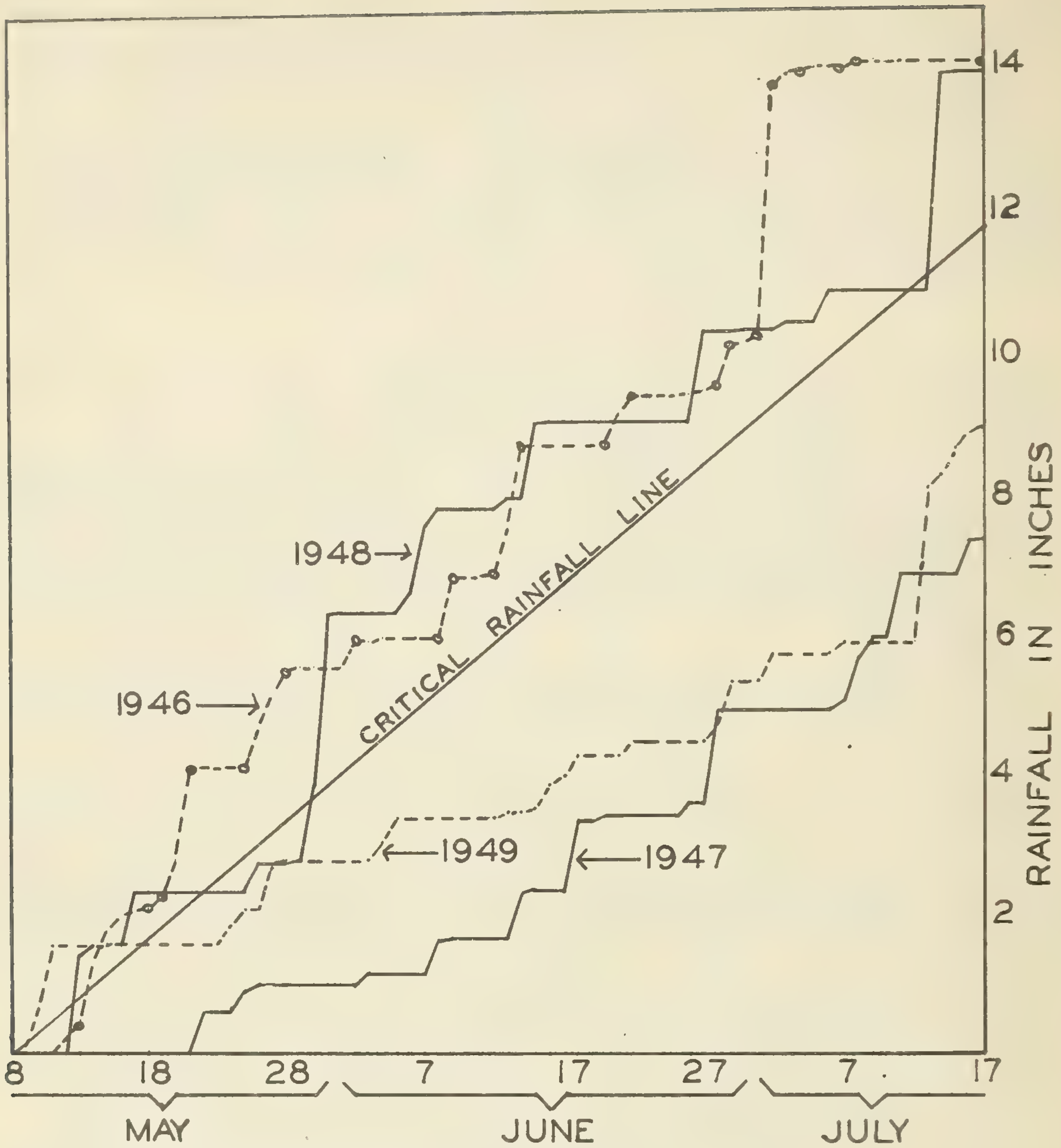

FIGURE 5—RAINFALL AT NORFOLK

In 1947 the rainfall was quite deficient and at no time did the cumulative rainfall get above the critical rainfall line. The forecasts for 1947 predicted blight would not be a factor. Only a trace of blight was observed on potatoes in the Norfolk area during 1947. This occurred during the latter part of June in a few fields of potatoes where air drainage was poor following abnormally low temperatures and over an inch of rain. These slight outbreaks were soon checked by a return of normal temperatures and did not reduce the yield.

In 1948 the cumulative rainfall line for the Norfolk area was quite similar to the rainfall line of 1946 when blight was serious. Blight was predicted and did cause considerable damage in the Norfolk-Cape Charles area in fields not sprayed or dusted as advised in the forecasts.

In 1949 the cumulative rainfall line was above the critical rainfall line for the first part of the forecasting period. Blight threatened but a change to drier conditions, drying winds and high temperatures after June 17 produced conditions unfavorable for blight. Blight was not a factor in 1949.

SUMMARY

The method developed for forecasting epiphytotics of late blight of potatoes and tomatoes in Eastern Virginia was used during the 1947, 1948 and 1949 seasons.

In 1947 the forecasting chart indicated no danger from blight due to deficiency of rainfall. Only a trace of blight was observed that year.

In 1948 the indications were for an outbreak of late blight and control measures were recommended. Blight did cause serious damage in the Norfolk and Cape Charles areas but growers who sprayed or dusted when directed by the forecasts obtained good control.

A year in which conditions were favorable for blight early but became unfavorable due to dry weather was experienced in 1949. Blight did get an early start in a few fields but was checked later by a deficiency in rainfall and high temperatures.

The forecasts made by this method are for the crop as a whole. They do not apply to individual fields in which because of low locations, windbreaks, a succession of local showers, or irrigation conditions are favorable for blight even though general conditions in the area are unfavorable.

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VIRGINIA TRUCK EXPERIMENT STATION, NORFOLK

SPORE TRAPS AS AN AID IN FORECASTING SEVERAL DOWNY MILDEW TYPE DISEASES[1]

R. A. Hyre[2]

INTRODUCTION

Fungicides, or at least some applications, are made to certain crops primarily for the control of downy mildew type diseases. If the occurrence of these diseases could be accurately forecast, considerable money, labor, and time could be saved during years of little or no disease. In other years, crop losses could be reduced.

To develop this idea a project was set up between the United States Department of Agriculture and fourteen Northeastern States, with headquarters at the University of Delaware, to establish facilities for forecasting some downy mildew type diseases. Along with other aids for realizing this goal, the use of spore traps has been quite intensively investigated and is the subject of this paper.

Some of the things we hope to learn from the use of traps are: one, the number of spores in the air under different environmental conditions; two, the distance spores may be disseminated and still be viable; and, three, whether a control program can be delayed until the presence of the inoculum in the area is established by means of spore traps.

METHODS

Vaseline-coated glass slides were used. One slide was used at a time and the usual procedure was to have the slides changed daily and mailed in at weekly intervals for examination.

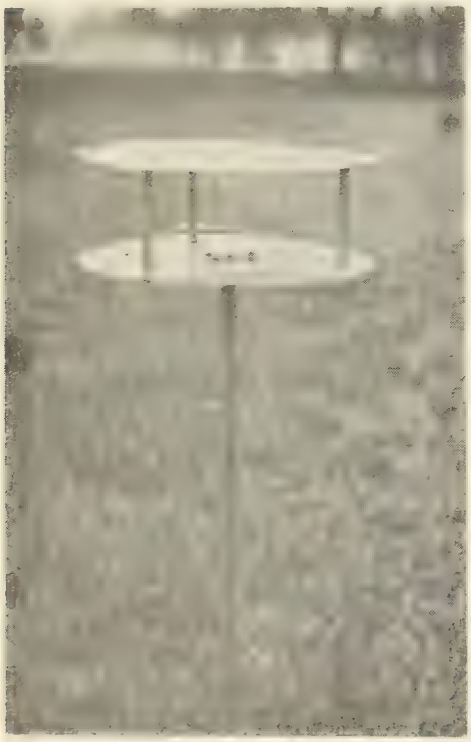

Figure 1. Standard pollen gravity sampling device.

At first the slides were located in a vertical position in vanes without protection of any kind. Few sporangia were obtained on the slides, so an investigation was made of the relative efficiency of different positions of the slide.

In addition to the vertical position, slides were located in a horizontal position with a stainless steel disc shield, nine inches in diameter, located five inches above the slide. This shield and a similar one placed one inch below the slide also were in the horizontal position. This arrangement, except that the discs were three inches apart, was later found to be the gravity trap recently adopted as standard for allergy studies (Fig. 1).

In a third arrangement the slide was inclined at a 45-degree angle and a shield was located six inches above the lower end of the slide. The exposed surface of the slide was kept into the wind.

At first, potted potato and cucumber plants were maintained in the greenhouse to be used in an attempt to check the viability of disseminated sporangia. They were not used, however, since so few sporangia were obtained on the slides and then only after infection occurred within a few miles of the traps.

EXPERIMENTAL RESULTS

Position of the Slide

Comparative laboratory and field studies were made of different positions of slides in respect to number of sporangia trapped.

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[1] Report of a study made under the Research and Marketing Act of 1946.

[2] The writer is indebted to the Delaware Agricultural Experiment Station for making available facilities for this study.

Laboratory Studies. Sporangia of Phytophthora phaseoli were shaken off infected pods into the air stream from a fan directed at slides located 12 feet away and within six inches of each other. One slide was located in a horizontal position (standard gravity trap) and the other in a vertical position (vane trap). The velocity of the air was 3.0 miles per hour.

In duplicated tests a total of 145 sporangia per square centimeter were obtained on the slide in the horizontal position to 52 on the slide in the vertical position. The ratio was 2.8 to 1.

Field Studies. In the field slides were located in a horizontal position, inclined 45 degrees, and in a vertical position. They were placed 30 inches above the ground, near each other, in a field of cucumber plants infected with downy mildew. The wind velocity varied up to 4.8 miles per hour. The slides were changed at 30 minute intervals for examination. A summary of the data is presented in Table 1.

Table 1. Efficiency of different positions of coated slides for trapping sporangia of Pseudoperonospora cubensis.

Position of slide	Sporangia per square centimeters in 5 hours	Mean number per hour	Ratio
Vertical	32	6.5	1.0
Horizontal	148	29.7*	4.6
Inclined 45°	179	35.7*	5.5

*LSD at the 5% level is 10.9.

From the data we see that a significantly greater number of sporangia were deposited on slides located in a horizontal position or when inclined 45 degrees than on slides placed in a vertical position. The respective ratios were 4.6 and 5.5 to 1.

In a second test in the same cucumber field 4.3 times as many sporangia were deposited on slides in the horizontal position compared with slides in the vertical position.

Thommen (4) found "considerable less" pollen grains deposited on slides held in a vertical position in a vane than on slides similarly prepared and located in a horizontal position in a somewhat sheltered place.

The standard gravity trap for allergy studies was used instead of the vane after it was found that more sporangia were deposited on slides in a horizontal position or inclined 45 degrees than on slides in a vertical position.

Sporangia in the Air

The presence of many sporangia a few feet in the air over fields with downy mildew diseases is easily shown by means of spore traps.

A gravity trap was located in a field of cucumbers containing downy mildew near Dover, Delaware. A record was made of the number of sporangia obtained in two and one-half hours in the late forenoon on two different days. The wind velocity did not exceed 4.8 miles per hour.

In the first experiment the slide was located 16 inches above the ground. An average of about 55 sporangia per square centimeter per hour was obtained.

In the second experiment the slide was located 30 inches above the ground. An average of 29.7 sporangia per square centimeter per hour was obtained.

Van Haltern (5), in Georgia, located slides among cantaloup vines with downy mildew and obtained as many as 41 sporangia per square centimeter per hour.

Distance Dissemination of Sporangia

Ten traps were set up in such locations (Table 2) as to expect to obtain information on the distance sporangia may be disseminated by the wind. No sporangia were obtained in a majority of the traps, however. In three vane-type traps sporangia of Phytophthora infestans were obtained. Careful surveys revealed the presence of late blight of potatoes or tomatoes at distances not less than 9, 5, and 3 miles from the traps at the time the sporangia were found.

Two gravity traps were located near a field of lima beans at Seabrook Farms[3], Bridgeton, New Jersey. One trap was located in a barren field 300 feet north of several acres of beans infected with downy mildew. The other trap was located on a shed 1100 feet (1/5 mile) east of the beans. Downy mildew was severe by September 15 when the traps were set up. Three sporangia were obtained on the slides located 1/5 mile to the east on one of two days when the wind was favorable and with a velocity up to 20 miles per hour. No sporangia were obtained in the trap located 300 feet north of the field in the one week the experiment was continued.

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[3] Thanks are due Mr. Louis J. Abrams, of Seabrook Farms, for operating these traps.

Since few sporangia were obtained in the studies reported here, even at moderate distances from their source, an attempt was made to check the efficiency of the traps used by means of volumetric apparatus, including a Wells Air Centrifuge, but the results are fragmentary to date.

Newhall (2), in New York, obtained sporangia of Peronospora destructor on glass slides at 1/3 mile from diseased plants. This was the maximum distance attempted. He obtained them, also, in petri dishes, up to 1500 feet in the air when flying over a heavily infected onion-growing area.

Use of Traps for Timing Control Measures

In order to test the value of traps for timing control measures a series of eight vane-type traps were located along the upper eastern coast of the United States in 1948. Two gravity traps were in operation in 1949[4].

The location of the traps in 1948 was as follows:

1. Virginia Truck Experiment Station, Eastern Shore Branch, Onley, Virginia.
2. Salisbury, Maryland.
3. Wyoming, Delaware, by a tomato field of Libby, McNeill, Libby Company.
4. Newark, Delaware.
5. Cape May, New Jersey, about one-quarter mile from the coast.
6. Riverton, New Jersey, on the Campbell Soup Company farm.
7. Bridgehampton, Long Island, near the coast.
8. Charlestown, Rhode Island, about one-half mile from the coast.

The trap at Cape May, New Jersey, was located in a non-agricultural area with prevailing winds from the Delaware Coast about 15 miles away.

The average air distance between stations, excluding Cape May, was about 65 miles; the overall distance was about 400 miles.

In 1949 the traps were located as follows:

1. Bridgehampton, Long Island, at the same location as in 1948.
2. Block Island, Rhode Island, on the Weather Bureau building.

Late blight of potatoes and tomatoes. The results of these studies bearing on the late blight disease of potatoes and tomatoes are presented in Table 2.

Thirteen sporangia of Phytophthora infestans were found on the slides --two at Onley, Virginia; three at Wyoming, Delaware; seven at Bridgehampton, Long Island; and one at Charlestown, Rhode Island. In every case, possibly with the exception of Onley, Virginia, late blight was present within 12 miles of the traps before the first sporangia were found on the slides.

The disease was present about 30 miles south of the trap at Onley on April 27 and continued to spread gradually. The first sporangium was not found until June 9, about six weeks later.

Late blight was found within five miles of the trap at Wyoming, Delaware, by June 4 but the first sporangia were not detected on the slides until 17 days later on June 21.

At Bridgehampton, Long Island, late blight was found three miles west of the trap on June 9 in 1948 but the first sporangium was observed on the slides 66 days later on August 14. No sporangia were obtained at this station in 1949.

Blighted potatoes were discovered 9 miles northeast of the trap at Charlestown, Rhode Island, on June 29 and the first and only sporangium was found 5 days later on July 3.

At the remaining stations, except Block Island, late blight occurred within 12 miles of the

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[4] The writer is indebted to the following for assistance with the traps:

Mr. L. T. Chandler, Virginia Agricultural Experiment Station, Eastern Shore Branch, Onley.
Mr. John Moore, Maryland Agricultural Experiment Station, Salisbury.
Mr. A. Lepore, Libby, McNeill, Libby Company, Wyoming, Delaware.
Mr. Joseph Long, Cape May, New Jersey.
Dr. S. G. Younkin, Campbell Soup Company, Riverton, New Jersey.
Mr. Robert Cetas, Cornell University, Bridgehampton, Long Island.
Mr. J. A. Walsh, Charlestown, Rhode Island.
Mr. James Decker, Block Island Weather Bureau Station.

Table 2. Results from spore traps for sporangia of Phytophthora infestans in 1948 and 1949 in connection with forecasting of late blight of potatoes and tomatoes.

Year Location	Interval traps were in operation	Number of sporangia found on the slides	Date first sporangium detected	Date late blight first found within 12 miles of the trap
1948				
Onley, Va.	May 27-Aug. 4	2	June 9	General by June 28
Salisbury, Md.	May 29-June 25	0	--	June 8
Wyoming, Del.	May 26-Aug. 16	3	June 21	June 4
Newark, Del.	May 24-July 8	0	--	June 24
Cape May, N.J.	June 5-Aug. 13	0	--	June 14
Riverton, N.J.	June 9-July 15; Aug. 4-Aug. 15	0	--	June 20
Bridgehampton, L.I.	June 18-July 15; Aug. 10-Aug. 24	7	August 14	June 9
Charlestown, R.I.	June 11-June 22; July 1-July 17	1	July 3	June 29
1949				
Bridgehampton, L.I.	June 7-Aug. 8	0	--	June 23
Block Island, R.I.	July 29-Aug. 15	0	--	?

traps from two to nine weeks while they were still in operation but no sporangia were detected on the slides. It is not known if late blight were present on Block Island.

These studies indicate that control measures for late blight of potatoes and tomatoes could not be delayed and be timed with the arrival of sporangia by air as determined by spore traps.

Downy mildew of cucumbers. No sporangia of Pseudoperonospora cubensis were found on the slides exposed at Wyoming, Delaware, in 1948. However, downy mildew on cucumbers was first observed on July 26 about four miles east-southeast of the trap and became so severe by August 10 that about 25 acres was abandoned. Slides were exposed until August 16. Timing of control measures by the spore traps would have failed completely in this case.

DISCUSSION

There are several rather serious objections to the practical use of spore traps for forecasting downy mildew type diseases.

For one thing, identification of detached sporangia on glass slides is not always an easy task. The size of sporangia of the same species may vary considerably. The morphology of different species may be quite similar. In this study use of prepared slides of known sporangia aided materially in identification of sporangia on the trap slides.

In the second place, actual efficiency of the slides is not known. Spore load required in the air before sporangia are detected on the slides is unknown. An attempt was made to determine this factor by means of volumetric apparatus including Wells Air Centrifuge, but data are fragmentary to date. Durham (1) gives a factor of 14.9 for Alternaria spores. When there is one spore per square centimeter on the slide surface, there are 14.9 spores per cubic yard of air.

Wind movements are quite a factor in spore trapping. Sporangia may by-pass a trap if it is not located in the path of the wind.

Even if spore traps accurately measure the number of sporangia present, they may not give a measure of the number of viable sporangia capable of causing infection. Thomas (3) has supplemented slides with potted plants in an attempt to measure "blight infection potential".

SUMMARY

A slide placed in a horizontal position (standard gravity trap) or inclined 45 degrees, with inclined surface into the wind, is more efficient for trapping sporangia of fungi causing downy mildew diseases of cucumber and lima beans than is a slide located in a vertical position in a

vane.

Numerous sporangia may occur in the air immediately over plants infected with late blight of potatoes and tomatoes, downy mildew of cucurbits, downy mildew of lima beans, and downy mildew of onions.

Sporangia of Phytophthora infestans apparently were wind disseminated for at least nine miles and those of Phytophthora phaseoli for at least one-fifth of a mile.

It is concluded that spore traps, as used in these studies, have little practical value for forecasting the diseases under consideration. It would be hazardous to rely upon them for timing a disease control program.

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CROP PLANT DISEASE FORECASTING PROJECT, PLANT DISEASE SURVEY

THE INFLUENCE OF CLIMATE ON THE DEVELOPMENT AND SPREAD OF PHYTOPHTHORA INFESTANS IN ARTIFICIALLY INOCULATED POTATO PLOTS[1]

Jack R. Wallin and Paul E. Waggoner[2]

Before outbreaks and subsequent spread of Phytophthora infestans can be predicted with reasonable accuracy, studies should be conducted on the frequency of occurrence of the weather conditions, especially temperature and humidity, that promote the development of P. infestans in the field. The late blight fungus lends itself to such studies because it requires a minimum number of hours of favorable temperature and humidity to produce sporangia. Shortly after they are produced, the sporangia require favorable conditions for germination.

The susceptibility of the sporangia to injury at temperatures above 80° F. and relative humidities below 90% narrows the range of favorable conditions under which P. infestans will flourish. The frequency of occurrence of such periods of favorable conditions during the growth cycle of the pathogen may be one of the basic factors in late blight forecasting.

During the 1948 and 1949 growing seasons, the temperature and humidity conditions associated with the development of P. infestans were studied in inoculated potato plots in Iowa and Indiana. The temperature and humidity conditions that prevailed during the initiation and spread of the pathogen were recorded. An attempt is made in this paper to analyze and interpret the data accumulated in such plots during the past two growing seasons.

MATERIALS AND METHODS

At Crystal Lake, in 1948, plantings were made on peat and mineral soil. The potato variety, Irish Cobbler, was used. The potatoes were planted in 12-row plots, 50 feet long and 40 feet wide. Two plantings were made on the peat soil and one on the mineral soil. The peat and mineral soil plots were about 1500 feet apart and the mineral plot was about 25 feet higher than the peat plot.

The inoculum was obtained from tuber halves infected with Phytophthora infestans. A sporangial suspension in water was sprayed on the foliage of four plants in the center of each plot.

The daily temperature range was obtained by maximum-minimum thermometers. A hand-aspirated psychrometer was used to obtain wet and dry bulb temperatures at 6-hour intervals. The data were taken at 1/2, 15, and 60 inches from the soil surface. A recording anemometer was used to obtain wind velocity data at 15 inches, 5 and 15 feet. Rainfall was measured with a standard Weather Bureau rain gauge.

At Bedford, Indiana, in 1949, potatoes and tomatoes were planted in the same plot in rows 50 feet long. Irish Cobbler potatoes and Rutgers tomatoes were used. Psychrometer readings were taken at levels of 1, 2, 3, 4, and 5 feet at 5 AM, 9 AM, 5PM, 9 PM. A hygrothermograph in an instrument shelter was used to obtain hourly temperature-humidity fluctuations. Rainfall was measured in the same manner as at Crystal Lake.

At Clear Lake, Iowa, in 1949, 42 rows of potatoes were planted in rows 54 feet long. The potato plants were 15 inches high when inoculated. After inoculation the temperature and humidity were recorded with a sheltered hygrothermograph placed 15 inches above the soil. The intensity and extensity of P. infestans at Clear Lake were determined by weekly counts of diseased top and bottom leaves in different rows three feet long.

All plots were inoculated with aqueous suspensions of sporangia.

THE CRYSTAL LAKE PLOT

1948

Induced Foliage Blight

(See Figure 13, page 33)

On June 21 at Crystal Lake, Iowa, the initial inoculations were made on potato foliage in the peat soil plot. Temperature, humidity, rainfall, and wind velocity records were taken from the

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[1] Report of a study conducted under the Research and Marketing Act of 1946. The investigation was conducted cooperatively between the Iowa and Indiana Agricultural Experiment Stations and the Division of Mycology and Disease Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture.

[2] Pathologist and Agent, respectively, Division of Mycology and Disease Survey, U. S. Department of Agriculture.

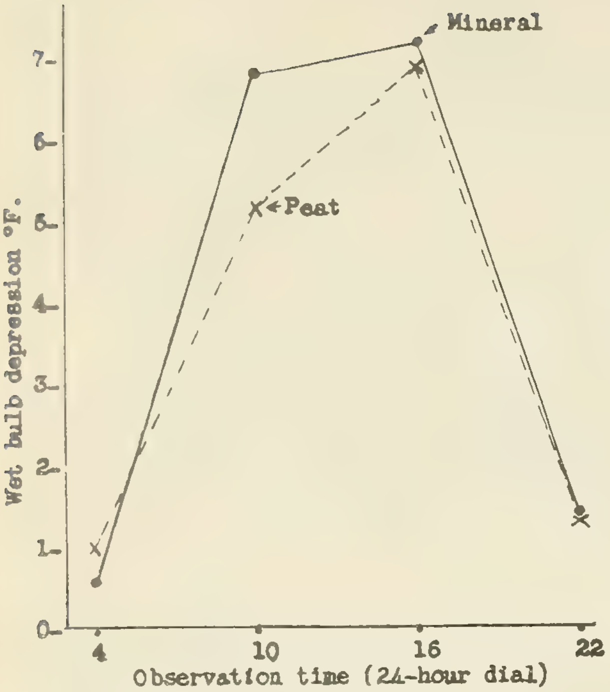

Figure 1. TEMPERATURE COMPARISONS BETWEEN MINERAL AND PEAT PLOTS FOR 7-DAY PERIOD AFTER INOCULATION. CRYSTAL LAKE, IOWA

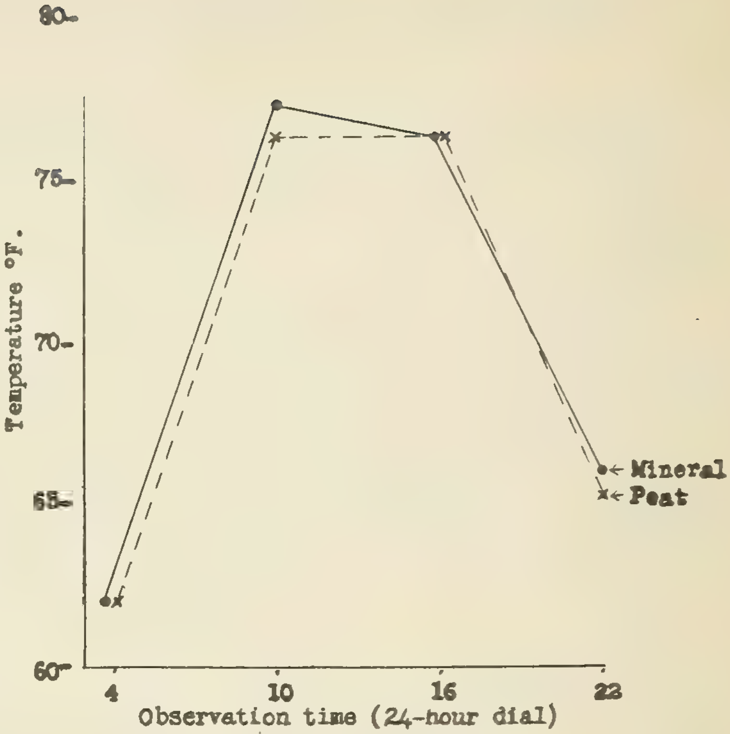

Figure 2. WET BULB DEPRESSION COMPARISONS BETWEEN MINERAL AND PEAT PLOTS FOR 7-DAY PERIOD AFTER INOCULATION. CRYSTAL LAKE, IOWA

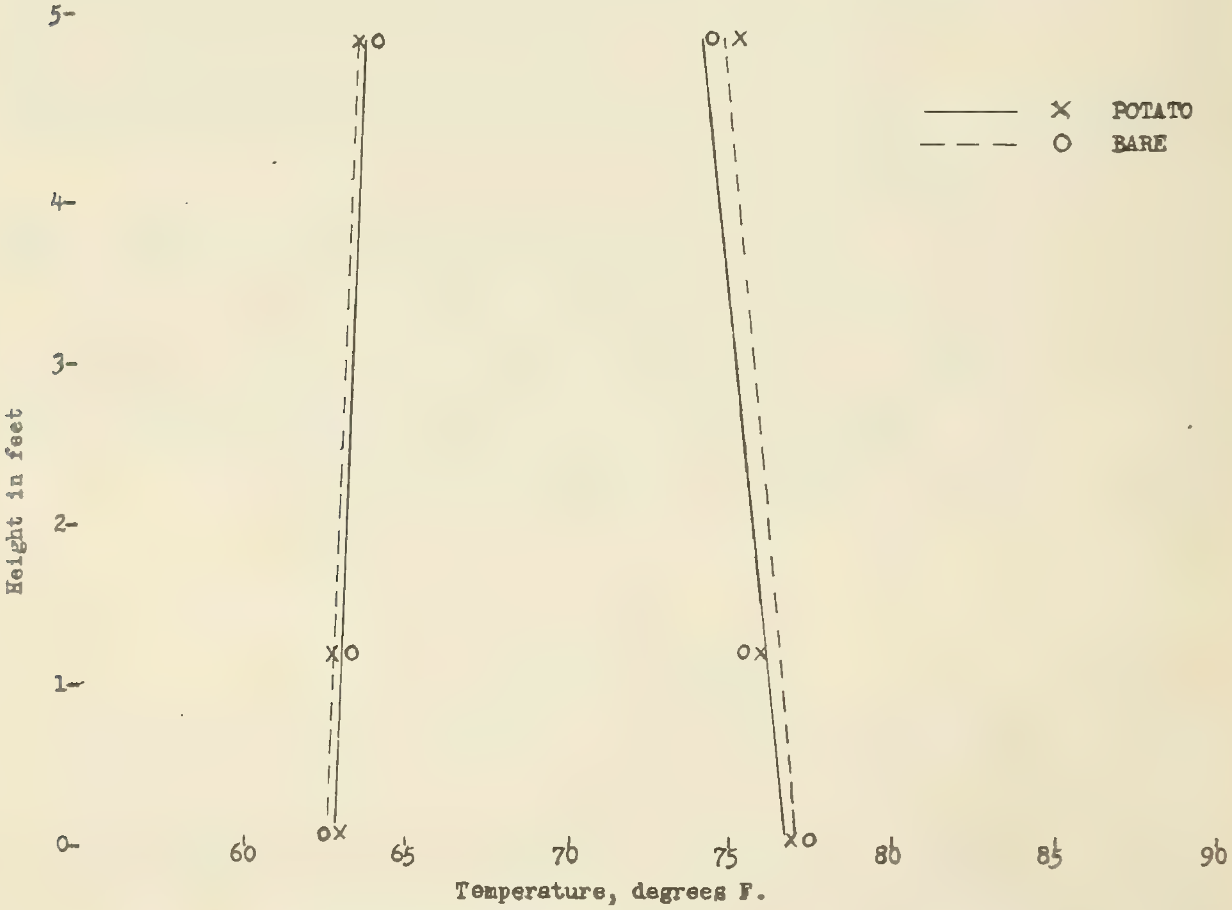

Figure 3. TEMPERATURE - HEIGHT RELATIONS FOR 8 DAYS AT CRYSTAL LAKE, IOWA. BARE AND POTATO PLOTS. JULY 1948

time the plants were inoculated until they were 95 percent defoliated. At the time of inoculation, the temperature was 79.5° F., and the relative humidity 77%. Four hours later that same evening guttation water covered the leaf margins and the temperature was 59° F. At 4 o'clock the following morning, the temperature was 65° F. and the relative humidity was 97%. During the next 18 hours 0.30 inches of rain fell. Every night for a period of ten days after inoculation, the potato leaves were wet with dew for a 12-hour period.

Seven days after inoculation leaf and stem lesions were apparent on the inoculated plants. At 4 AM on the eighth day, diseased leaves were examined and found to have an abundance of sporangia on the lower surface. At the same time small lesions were apparent on the lower leaves of the plants in the adjoining row to the south. On the ninth and tenth day, temperature-humidity conditions during the night were favorable for reinfection.

On the 9th of July, an aqueous sporangial suspension of P. infestans was sprayed on four potato plants in the mineral and in the second peat planting. The plants were inoculated at 4 PM, just after a light rain. At the time of inoculation, the temperature and relative humidity on the peat plot were 85° and 64% respectively; on the mineral plot the temperature was 84.5° and the relative humidity 64%. By 10 PM that evening the leaves in both plots were covered with dew. During the critical first few hours after inoculation, the conditions were nearly the same in both plots. For the next two nights in succession, the leaves were wet with dew in both plots. Furthermore, the potato foliage on both plots was wet for two consecutive days on the fourth and fifth day after inoculation. Seven days after inoculation, lesions were evident on the top and bottom leaves of the four inoculated plants in the peat planting. No late blight symptoms were observed on the inoculated plants in the mineral soil planting. The temperature and humidity relationships during the seven-day period from inoculation to obvious infection are shown in Figures 1 and 2.

During the first five days, there were only small differences in temperature and humidity between the two plots. The difference in humidity between the two plots was greater on the sixth and seventh days. However, these differences probably occurred too late to influence initial infection.

By July 30, three weeks after inoculation, 100 percent of the plants in the peat soil planting were blighted and were well defoliated. Only a few relatively young leaves remained on the tops of the plants. In the mineral planting, there were no symptoms of potato blight. The plants were green and were relatively intact except for a small percentage of leaves diseased with early blight.

The Relationship of Temperature and Humidity to the Development of the Late Blight Pathogen

The temperature and humidity data obtained during the six-week period following inoculation were compared and analyzed for the peat and mineral plots.

First, analyses were made of temperatures obtained at different heights above ground at four times a day for eight days. Temperature readings made over fallow ground were used to compare with those obtained over plant cover. These relationships are shown in Figure 3.

As shown in this figure, there were great differences between day and night temperatures and some differences between bare ground and potato cover. In the daytime, temperatures were higher at the lower level and at night were cooler at the lower level.

For additional information on the temperature-blight relationship, soil temperatures were taken for a three-day period and were compared with the air temperatures. The observations made on the mineral and peat potato plots are shown in Figures 4 and 5.

The soil temperatures were higher at night and lower in the day than the air temperatures. During the three-day period, the peat soil temperatures were consistently cooler than the mineral soil temperatures. The growth and development of Phytophthora infestans on the foliage was probably not influenced by the soil temperatures. Undoubtedly, the air temperature is the determining factor.

The peat and mineral plot temperatures at four times a day at three levels above the soil were compared. The data are summarized in Table 1.

As shown in the table, the temperature differences between the two plots were significant. The peat plot temperatures were consistently lower than the mineral. However, the differences between the plots for a given time were apparently inconsequential to the initiation of late blight. For example, the greatest mean difference in temperature between the two plots was 1.38° F. At 10 AM the 1/2-inch level on the mineral plot was 1.38° F. warmer than the same level on the peat plot. Hence, there was not a temperature difference between the plots sufficiently great to explain why blight appeared on the peat and not on mineral potatoes.

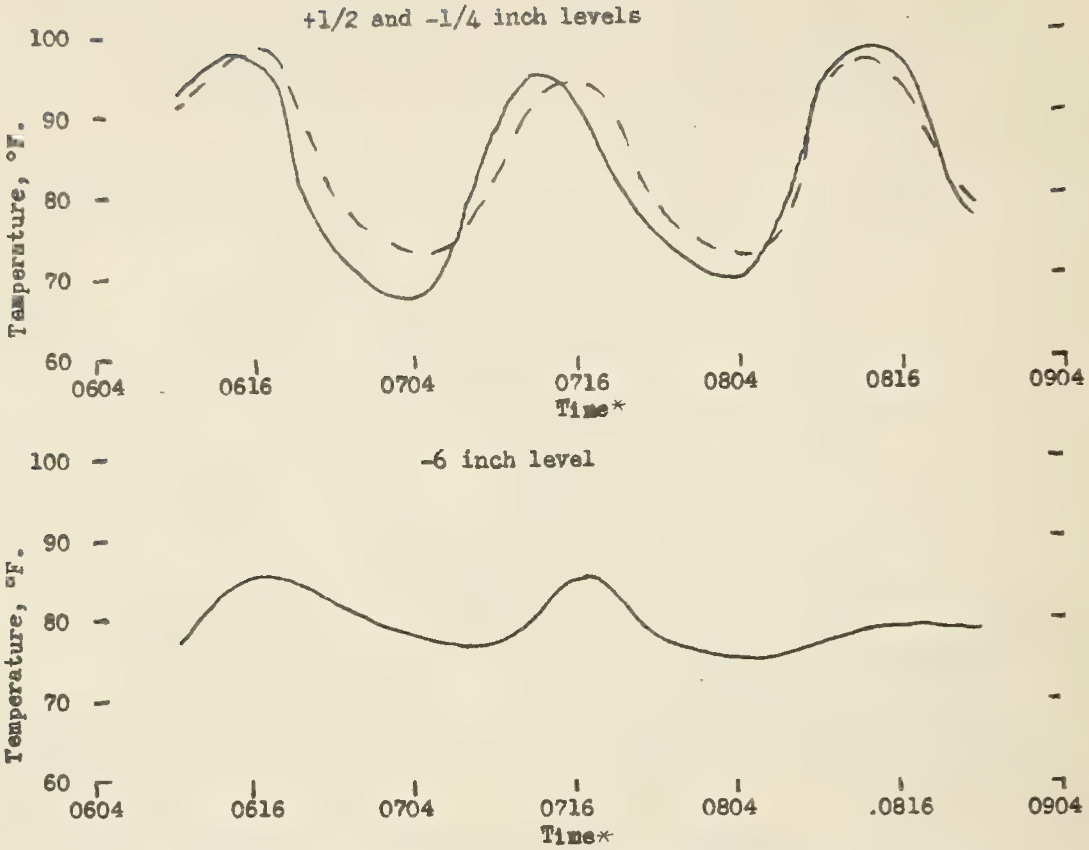

Figure 4. SOIL AND AIR TEMPERATURES: MINERAL PLOT, CRYSTAL LAKE, JULY 1948

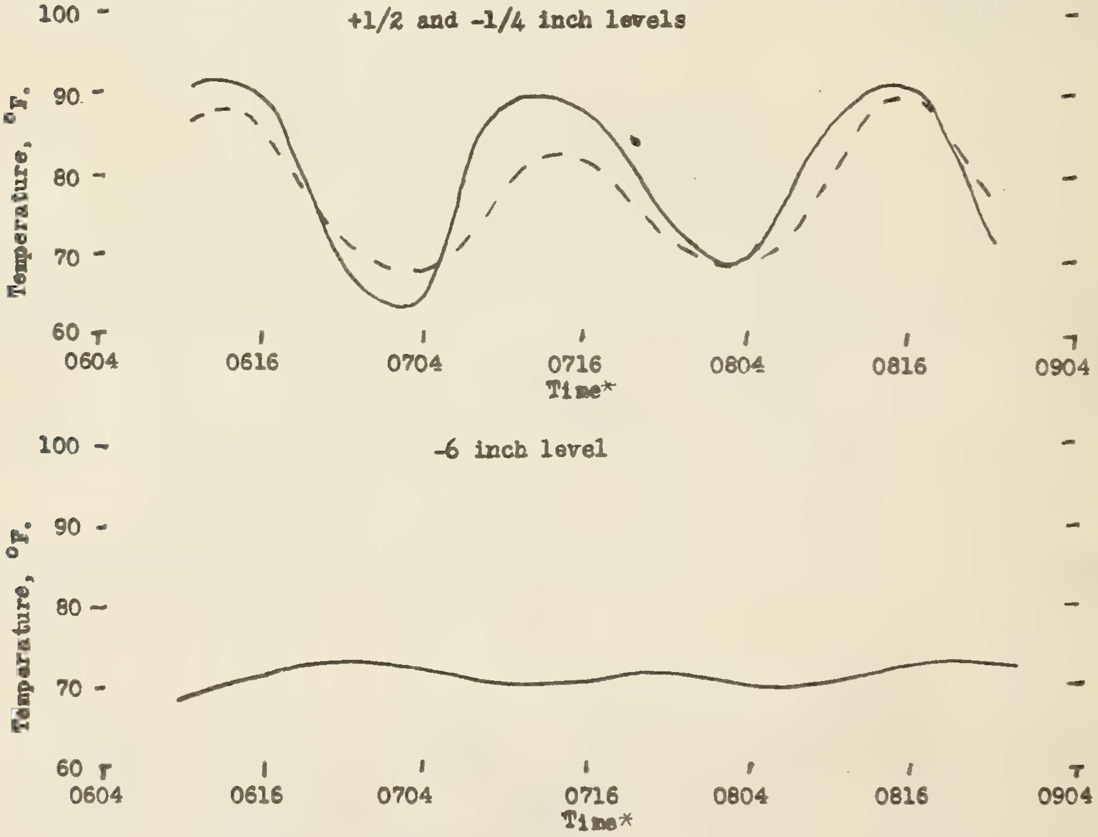

Figure 5. SOIL AND AIR TEMPERATURES: PEAT PLOT, CRYSTAL LAKE, JULY 1948

(*Time: 0604 = July 6, 4 AM; 0616 = July 6, 4 PM; etc.)

Table 1. Summary of the mineral and peat plot temperature data at six hourly intervals at three different levels.

Time	Level	Mean difference	t- value
4:00 A. M.	1/2 inch	1.34	3.55**
	15 inches	1.15	3.68**
	60 inches	0.95	2.28*
10:00 A. M.	1/2 inch	1.38	3.67**
	15 inches	.96	2.36*
	60 inches	.37	0.97
4:00 P. M.	1/2 inch	.69	1.23
	15 inches	.65	1.16
	60 inches	.36	1.03
10:00 P. M.	1/2 inch	1.34	4.09**
	15 inches	.76	2.37*
	60 inches	.91	2.49*

$* = t_{20,\,05} = 2.1$
$** = t_{20,\,01} = 2.8$

The humidity data obtained with the hand-aspirated psychrometer were compared for their role in blight development on potatoes in both plots. Comparisons were made of the wet bulb depressions for the potato plots and bare ground as well as for the peat and mineral soil plots at 4 times and 3 levels from the soil. The bare ground and potato plot comparisons are shown in Figure 6. As shown in the figure there was little difference in humidity from the 1/2-inch to the 60-inch level either over bare ground or potato cover.

Table 2. Summary of mineral and peat plot humidity data at six hourly intervals at three different levels.

Time	Level	Mean difference	t - value
4:00 A. M.	1/2 inch	-.15	2.2*
	15 inches	+.07	0.81
	60 inches	+.05	0.26
10:00 A. M.	1/2 inch	-1.85	4.57**
	15 inches	-1.64	3.7**
	60 inches	-.81	1.7
4:00 P. M.	1/2 inch	-1.52	3.1**
	15 inches	-.60	1.5
	60 inches	-.10	.26
10:00 P. M.	1/2 inch	-.59	3.2**
	15 inches	-.29	1.3
	60 inches	-.71	3.06**

$* = t_{20,\,05} = 2.1$
$** = t_{20,\,01} = 2.8$

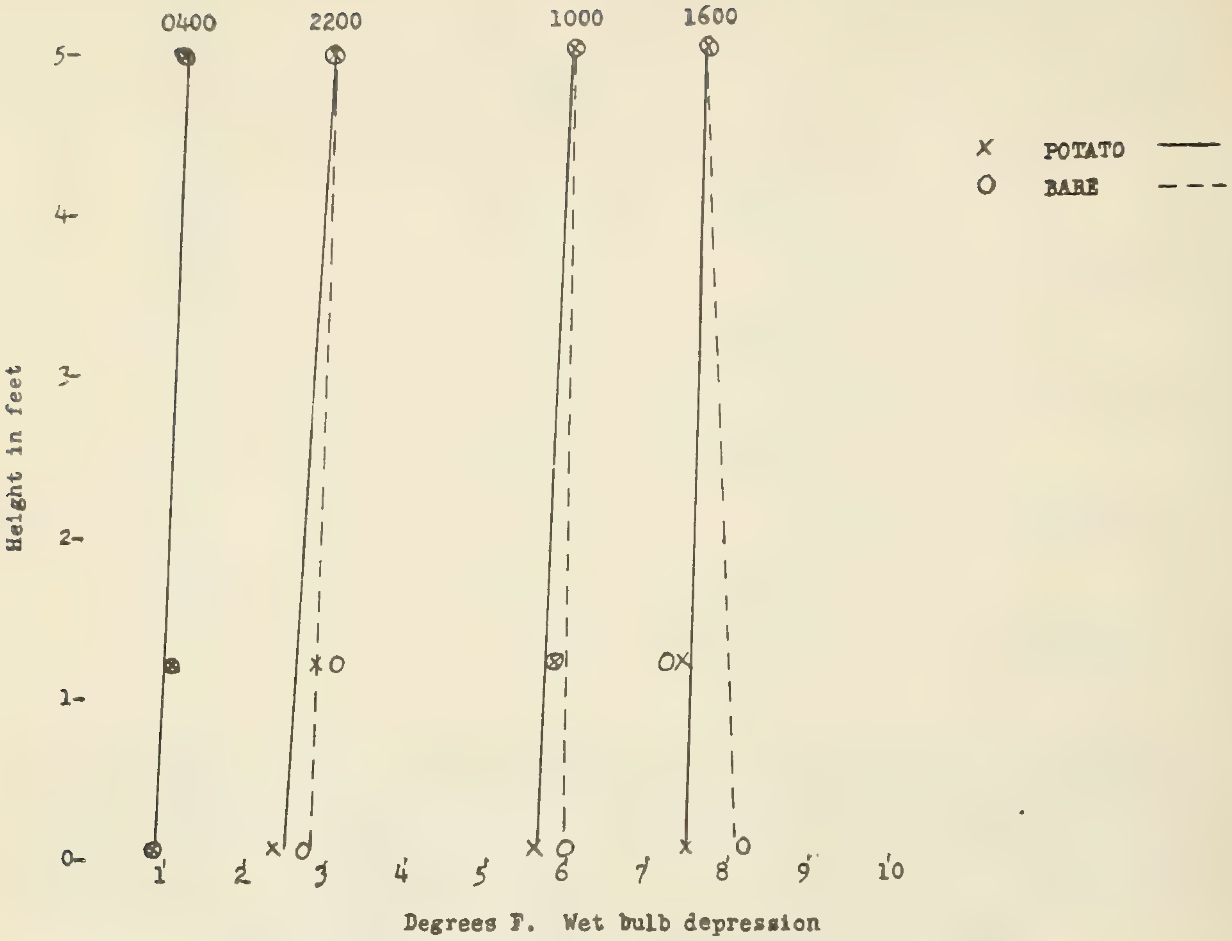

Figure 6. DEGREES F. WET BULB THERMOMETER DEPRESSION - HEIGHT RELATIONS FOR 8 DAYS AT CRYSTAL LAKE, IOWA. BARE AND POTATO PLOTS. JULY 1948.

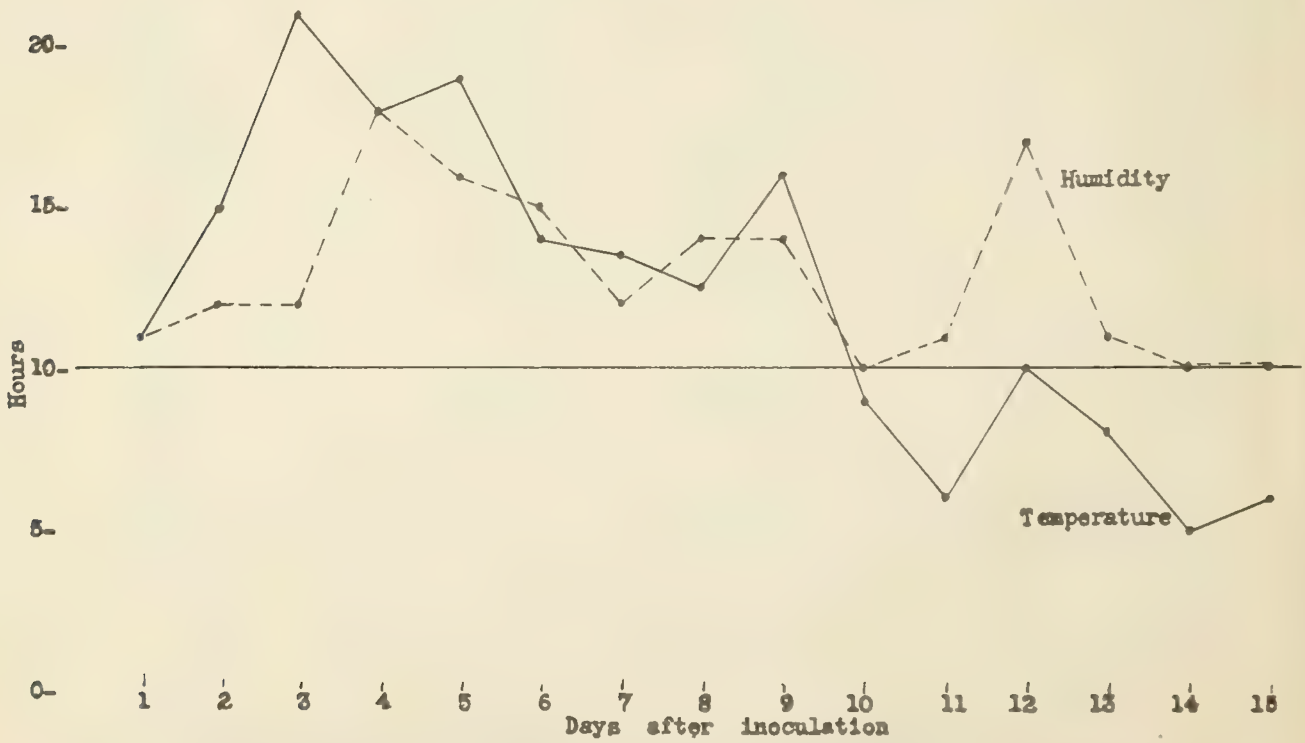

Figure 7. NUMBER OF HOURS OF TEMPERATURE 75°F. OR BELOW AND HUMIDITY 90% OR GREATER: CLEAR LAKE, IOWA

A summary of the peat and mineral soil plot comparisons is shown in Table 2. Of particular interest is the fact that for all times at the 1/2-inch level, the mean difference in wet bulb depression between the plots was significant. However, the mean difference between plots at a given time and level was small and probably was inconsequential to late blight occurrence. Certainly, the differences in wet bulb depression in themselves would not explain why the blight pathogen developed in the peat potatoes and failed to develop in the mineral potatoes.

The greatest difference between the plots was that the peat potato plants were much more rank and vigorous. The foliage canopy of the peat plot potatoes tended to retain dew longer in the morning than the less vigorous mineral plot plants. Some of the peat potato leaves were more shaded and probably were cooler than those of the mineral potatoes.

Spread of Phytophthora infestans During Six Weeks Period

Diseased leaf counts were taken in the peat soil area to determine the intensity and extensity of the blight pathogen during the six weeks period following inoculation. Nine different collections of 500 green leaves each were counted and of each collection the number of blighted leaves was determined. Within the inoculated plot, 41 percent was the highest disease count obtained from the remaining green leaves. Of the 4500 leaves counted, 24 percent were diseased.

Diseased leaves were counted in the plots to the east, south and west. In the potato plot 50 feet to the east of the inoculated planting, only 5 percent of the plants were infected. Of 2000 leaves counted, 2.5 percent showed late blight lesions. Only 1 percent of the leaves had late blight 516 feet to the southeast of the disease garden. These low percentages indicated that the fungus did not spread very far to the east after a period of six weeks. In the potatoes adjoining the south border of the disease garden 95 percent of the plants were infected 333 feet from the disease plot. Naturally, in the rows immediately adjoining the inoculated planting, 100 percent of the plants were infected and only a few green leaves remained on the vines. Of 2500 leaves counted in this planting, 19 percent were infected with P. infestans. These observations indicated that the fungus spread more rapidly to contiguous plants than to plants separated by wide gaps of non susceptible host material.

Late blight lesions were found in potatoes to the west of the inoculated plants. The intensity of the late blight pathogen decreased as the distance increased away from the inoculated potatoes. Ten feet from the inoculated plot 95 percent of the plants were infected; while 335 feet from the initially inoculated plot, only 1 percent of the plants were diseased. Such a small percentage of diseased plants indicated a very slow rate of spread over a six-weeks period.

Potato plants across the road, 550 to 600 feet northwest of the inoculated plot, were observed periodically for late blight symptoms. As of July 30, when 100 percent of the plants in the inoculated plot were infected, 2 percent of the plants across the road were infected. By August 15, in some areas of the field, 75 percent of the plants were diseased. The indications were that P. infestans spread very slowly for short distances from the initially infected plants. At least these results indicated that under these conditions the pathogen was not readily disseminated over long distances, because no late blight lesions were found in potato fields 1500 to 2000 feet from the disease plot.

The Comparison of Crystal Lake Plot, Forest City and Britt Daily Mean Temperatures

Before attempting to employ Weather Bureau data daily mean temperatures in formulating late blight forecasts the daily mean temperatures taken in a potato field should be compared with those of nearby Weather Bureau stations. In order to ascertain the relationship of data obtained from a potato field with those from nearby weather stations, comparisons were made of the mean daily temperatures from Britt, Forest City, and Crystal Lake. Britt and Forest City were 10 to 13 miles respectively, from the potato plot at Crystal Lake.

The mean temperatures for 22 days were compared. For the 22-day period, the average temperatures were: Crystal Lake, 69.4; Britt, 73.3; and Forest City, 71.8. The average temperature of the Crystal Lake plot was 3.9° F. lower than the Britt average. The temperature of the three locations were analyzed as shown in Table 3.

The analysis indicated that the differences between locations were highly significant. The greatest average difference of 3.90° F. was between Crystal Lake and Britt. This difference between these locations indicated that on some days the temperature was considerably cooler at Crystal Lake. Although the average temperature difference of 2.4° F. between Forest City and Crystal Lake was not so great, the temperatures were lower at the potato plot.

Table 3. Analysis of variance of mean daily temperatures at Britt, Forest City and Crystal Lake, Iowa.

Source of Variation	DF	SS	MS	F-value
Britt vs Crystal Lake	1	169.0	169.0	46.2**
Date	21	1159.0	55.2	15.3**
Location x date	21	77.0	3.66	
Total	43	1405		
Crystal Lake vs F. City	1	63.0	63.0	10.5**
Date	21	1227.0	58.4	9.7**
Location x date	21	128.0	6.0	
Total	43	1418		
Britt vs Forest City	1	25.0	25.0	7.6*
Date	21	1434.0	40.4	12.2**
Location x date	21	70.0	3.3	
Total	43	1529.0		

* 5% level of significance
** 1% level of significance

These differences in temperature between the potato field and the weather stations indicate that it is safer to rely on the temperature data taken in the potato field.

THE CLEAR LAKE, IOWA PLOT

The Influence of Temperature and Humidity on the Initiation and Spread of Phytophthora infestans in Field Plot Potatoes

On June 8, a sporangial suspension of P. infestans was sprayed on nine plants in the Clear Lake potato plot. These plants were tagged and observed daily for late blight symptoms. Twelve days later, the plants were free of blight lesions. During the seven-day period after the plants were inoculated there were only four hours when the relative humidity was 90% or greater although there were many hours of temperature 75° F. or less. Dry conditions prevailed for 12 days and no blight symptoms were noted.

On June 20, the plants were sprayed again with P. infestans sporangia. Within a week, the inoculated plants and several adjoining plants were generally infected with the pathogen. The successful foliage infection by the pathogen was enhanced by the favorable temperature-humidity conditions that occurred the night of inoculation. The temperature-humidity conditions obtained for the 15 day period after inoculation are illustrated in Figure 7.

The number of hours of temperature 75° F. or less was high, especially for eight days after inoculation. There were over 10 hours per day for eight days of relative humidity 90% or greater. These favorable conditions promoted the growth and development of the late blight fungus and enhanced secondary infection after the second inoculation period.

Counts of diseased leaves were made June 14, 21 and 28, July 5, 12 and 19. The results of the counts are depicted diagrammatically in Figure 8.

On June 14 and 21, no blight was found in the plot. On June 28, late blight was prevalent in the center of the plot. By July 19, blight extended over the whole plot and the plants were dying. The pattern of spread was from the center of the plot to the periphery. There was no evidence that the pathogen jumped from the center of the plot to the edges of the plot. On the contrary, there was a gradual spread of the fungus to surrounding plants. During the four-week period, after the second inoculation, the rainfall-temperature conditions were very favorable for blight development. Figure 9 illustrates the weekly incidence of rainfall on the plot accumulated from both times of inoculation.

As shown in the above figure, the plot received at least an inch of rainfall each week after the second inoculation. In addition, dew was noted for all except two nights. Under the environmental conditions, the blight extensity in the plot nearly doubled each week because there were cycles of favorable temperature and humidity conditions coincident with sporulation cycles of the pathogen.

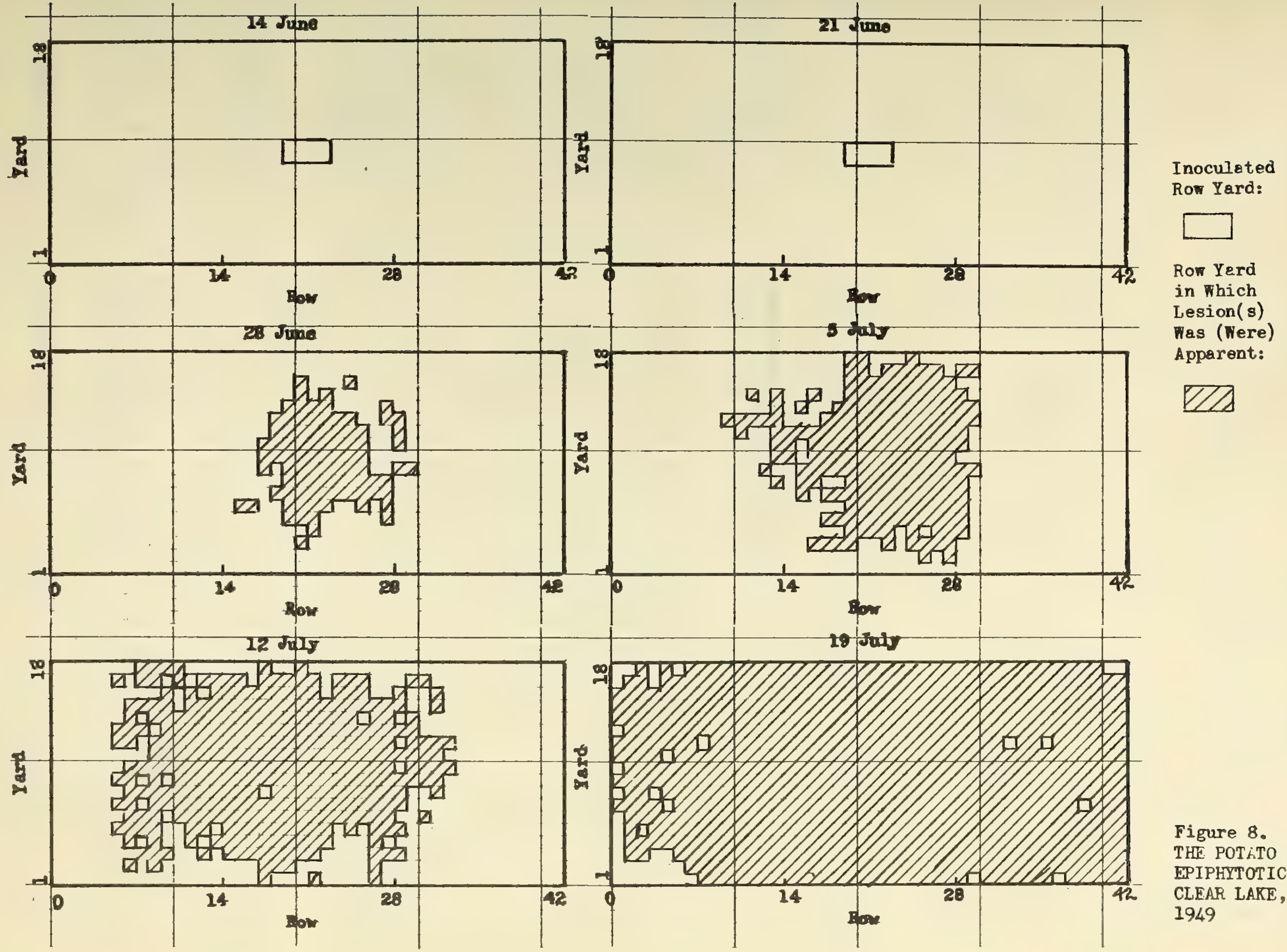

Figure 8.
THE POTATO LATE BLIGHT
EPIPHYTOTIC AT
CLEAR LAKE,
1949

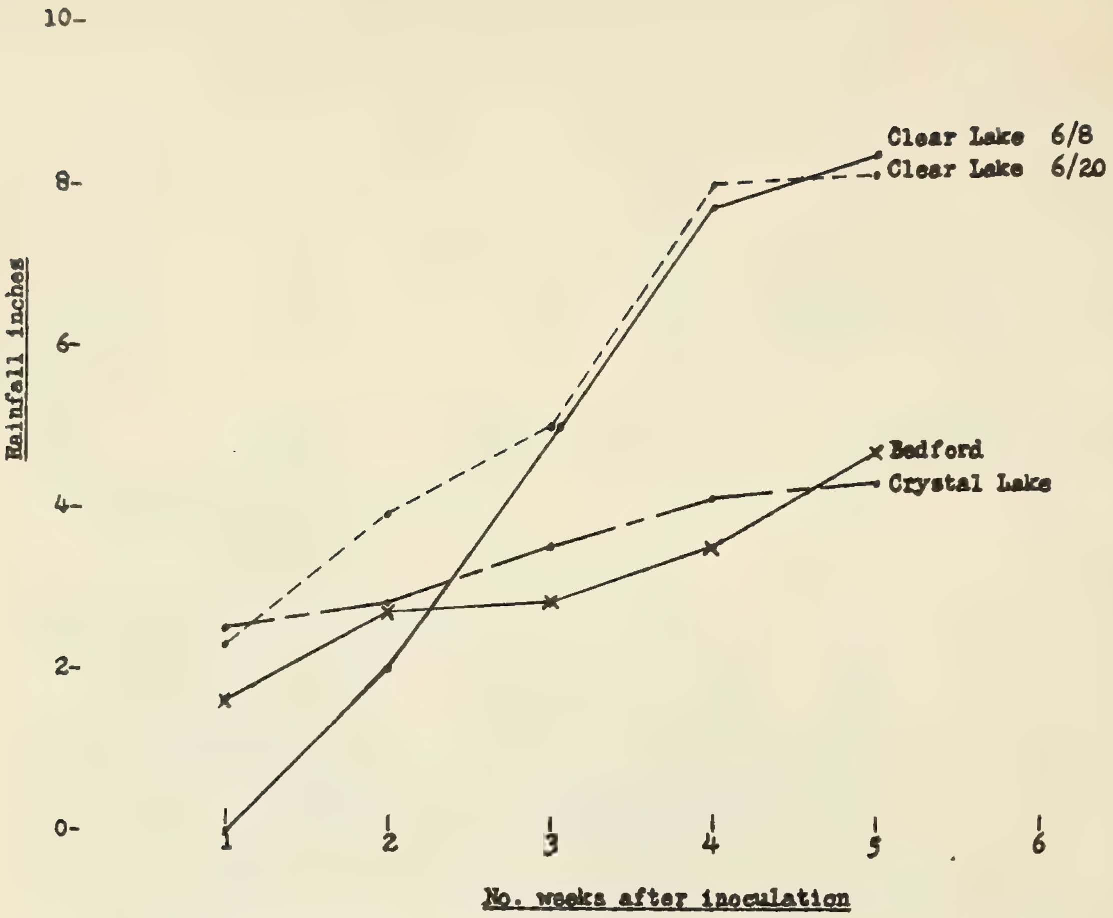

Figure 9. CUMULATIVE RAINFALL AT CLEAR LAKE, IOWA, CRYSTAL LAKE, IOWA AND BEDFORD, INDIANA

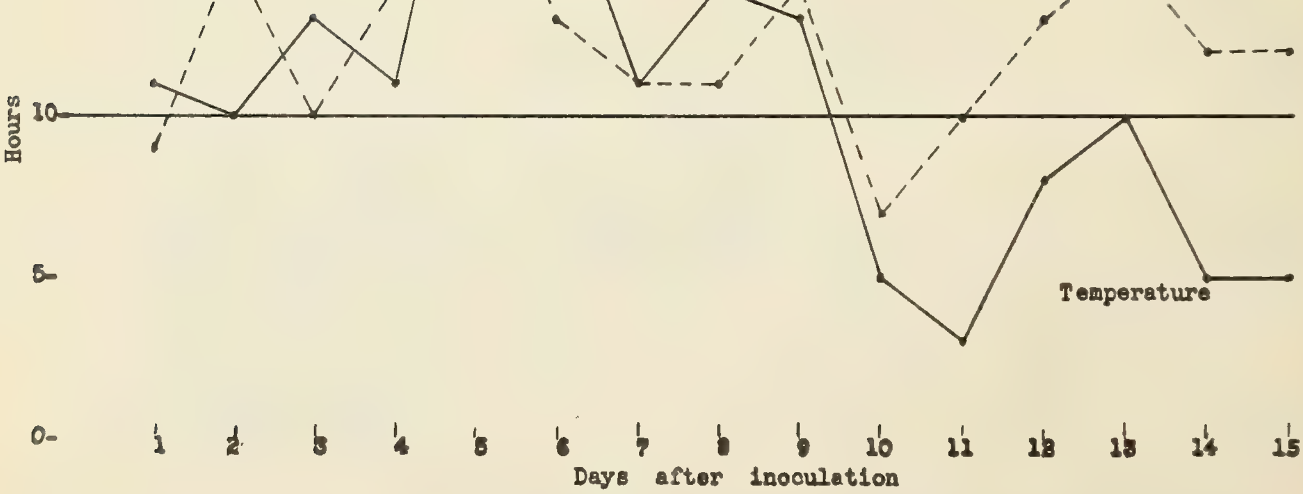

Figure 10. NUMBER OF HOURS OF TEMPERATURE 75° F. OR BELOW AND HUMIDITY 90% OR GREATER: BEDFORD, INDIANA

Temperature-Humidity Conditions Associated With Viability of Sporangia Trapped on Live Potato Leaflets

As a method of sampling the number of viable sporangia of *P. infestans* adrift at various periods of the day, live potato leaflets were collected from the disease plot at 3, 6, 9 AM and 12 Noon. The leaflets were placed immediately in moist petri dishes and held at 15° C. for a week at which time the number of leaflets with lesions was noted. The presence of *P. infestans* was diagnosed by the occurrence of sporangia on the surface of the lesion.

The temperature, relative humidity and the number of infected leaflets obtained at the four collection periods are shown in Table 4.

Table 4. Number of blight lesions developing from potato leaflets picked at four times on two days.

July 12

Time	03		06		09		12	
	Number infected leaves		Number infected leaves		Number infected leaves		Number infected leaves	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
	4	3	5	5	4	9	1	6
Temperature	58		64		78		83	
Humidity	100		100		70		54	

July 19

	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
	1	15	1	14	3	14	0	12
Temperature	59		59		74		79	
Humidity	100		100		80		62	

The data indicated that as the temperature increased and humidity decreased, fewer sporangia remained viable on the top leaves. However, at the noon picking on the bottom leaves nearly as many lesions appeared as on the leaves picked earlier. These preliminary trials indicate that such leaf sampling may be used in determining the presence or absence of viable sporangia of *P. infestans* in the field. In addition these results suggest the need for information on the longevity and viability of sporangia produced and disseminated at various times of the day under varying conditions of temperature and humidity.

THE BEDFORD, INDIANA PLOT

A study of climatic factors associated with blight development was conducted in a potato-tomato plot at Bedford, Indiana. At the time of inoculation, June 16, the plants were about 15 inches high and had a very open foliage canopy. As a result, most of the leaves were unshaded at some time during the day. The potato and tomato plantings were made in the same plot in order to study the spread of the late blight fungus from inoculated potato foliage to the tomato.

The Initiation of Potato Late Blight

Nine potato plants in the center of the plot were inoculated with sporangia of *P. infestans*. The tomato plants were not inoculated. The inoculated plants were observed daily for blight symptoms. On the third and fourth day after inoculation atypical symptoms were apparent and sporangia were observed on the surface of the lesions. Over half the leaves of the inoculated plants were infected and the stage was set for an epiphytotic of late blight. However, at the critical time during sporulation, high temperatures were dominant and the pathogen perished. The temperature-humidity conditions associated with the development of the pathogen are shown in Figure 10.

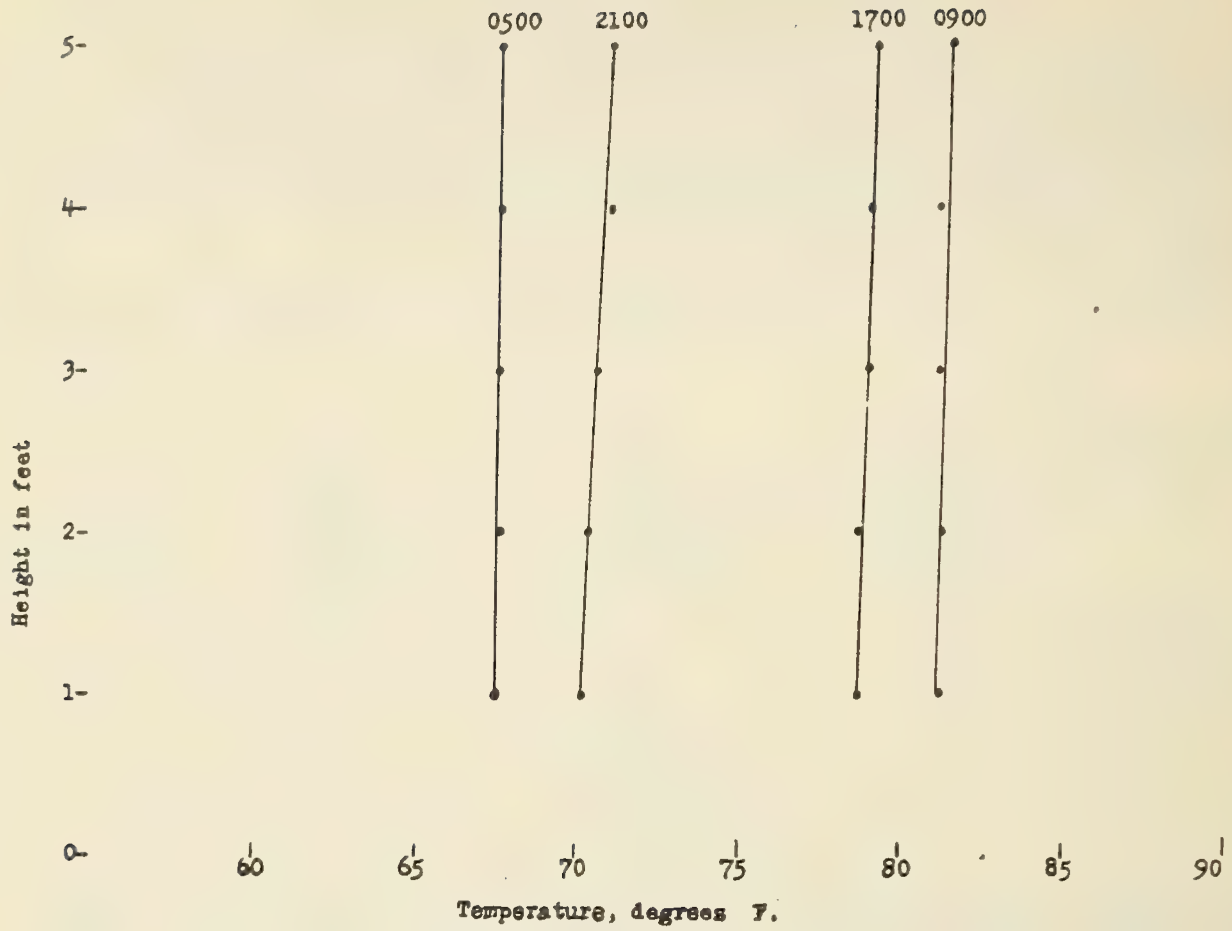

Figure 11. TEMPERATURE - HEIGHT RELATIONS FOR 14 DAYS AT BEDFORD, INDIANA, JUNE-JULY 1949. TOMATO - POTATO PLOT.

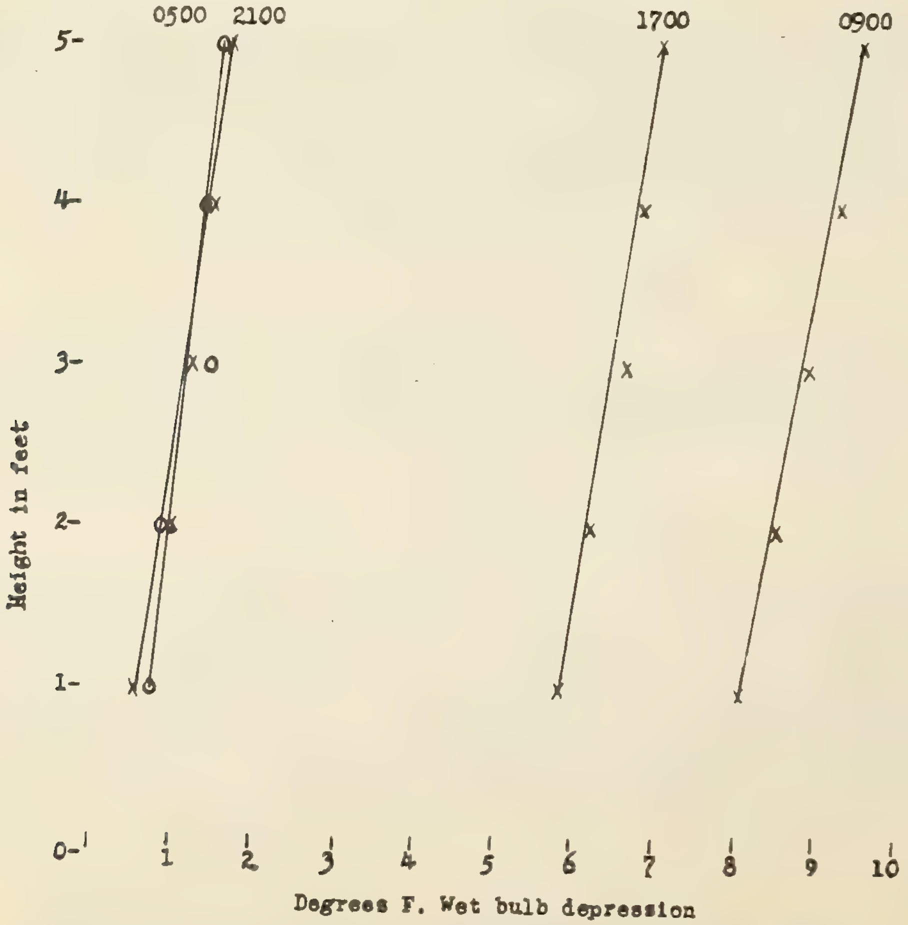

Figure 12. DEGREES F. WET BULB THERMOMETER DEPRESSION - HEIGHT RELATIONS FOR 14 DAYS AT BEDFORD, INDIANA, JUNE-JULY 1949. TOMATO - POTATO PLOTS

The data indicated that temperature and humidity were favorable to P. infestans development for the first nine days after inoculation. For the next three days, high temperatures prevailed. The maximum temperatures were above 90° F.; therefore, because of the sparse foliage cover the temperatures of the leaves exposed to the sun probably ranged well above 90° F. On the 14th and 15th day after inoculation, high temperatures again were dominant. During the high temperature periods the relative humidities were favorable.

Apparently nine days after the plants were inoculated, the prevailing high temperatures began to kill the new spore crop and prevented secondary infection. The high temperatures occurred during the initial sporulation on the inoculated plants. Undoubtedly, P. infestans had been killed by the high temperatures 13 days after the presence of blight was noted on the inoculated plants. Repeated attempts to isolate the pathogen from the initial lesions were unsuccessful. As the growing season progressed, P. infestans did not develop in either the potato or tomato plants.

The Relationship of Temperature and Humidity to Height Above Plants

Although the late blight fungus was killed shortly after it was initiated, temperature and humidity data were taken at five levels above the soil. The data for 14 days after the potato foliage was inoculated were analyzed for difference in temperature associated with height above ground. The summary of the analysis is shown in Table 5.

Table 5. Analysis of variance of temperature-height slopes for fourteen days at four locations. Bedford, Indiana.

Variation due to:	DF	SS	MS	F-value
Locations	3	3.9	1.3	0.2
Times	3	73.7	24.5	4.3**
Days	13	376.4	29.0	5.1**
Interaction of				
Location x times	9	29.4	3.26	0.57
Location x days	39	134.3	3.44	0.60
Days x times	39	481.0	12.33	2.2**
Days x times x locations	117	666.7	5.70	
Total	223	1765.4		

** One percent level of significance.

As indicated by the analysis, there were highly significant differences between the temperature slopes at the four times and for the series of days used. Although the slopes for the four locations differed significantly with time of day, the difference in temperature between the one foot level and five feet was probably inconsequential to the growth of P. infestans. For the 14-day period, the greatest difference in temperature between the two extreme levels was five degrees. The slopes obtained at four times for the 14-day period are shown in Figure 11.

Similarly, the humidity data were analyzed for differences in slopes of the wet bulb depression with time of day and with days. A summary of the analysis is shown in Table 6.

The analysis indicated that there were highly significant differences between slopes at the four times and between days for the 14 days. There was no evidence of increasing humidity at the lower levels. The great differences were at the various times as illustrated. The relationships of the five levels above ground to the depression of the wet bulb thermometer are shown in Figure 12.

DISCUSSION

A close examination of the findings from the above mentioned trials suggests that more information is needed on the occurrence of specific weather conditions that favor the development of Phytophthora infestans. The fungus grew and spread in the field under daily conditions that were not particularly optimum during the 24-hour period.

Table 6. Analysis of variance of humidity-height slopes for fourteen days at four locations.[a] Bedford, Indiana.

Variation due to:	DF	SS	MS	F-value
Location	3	11.5	3.8	0.93
Time	3	80.5	26.8	6.5**
Day	13	316.6	24.3	5.9**
Interaction of				
Location x time	9	60.4	6.7	1.6
Location x days	39	213.8	5.5	1.3
Day x time	39	590.2	15.1	3.7**
Day x time x location	117	484.1	4.1	
Total	223	1757.1		

** One percent level of significance.

[a] The difference between wet and dry bulb thermometer temperature readings was used as the humidity measurement.

The data obtained at Crystal Lake, Clear Lake, and Bedford indicated that the air temperature immediately surrounding the plants can be expressed from temperatures recorded five feet above the plot. The same is true for the recording of the atmospheric humidity surrounding potato plantings.

The initial successes in initiating late blight epiphytotics in potato plots indicated that such plots, in conjunction with frequent blight surveys and other weather data collected from the general area surrounding the plot, might be utilized in preliminary late blight forecasting. For example, the late blight disease garden at Crystal Lake, in 1948, served as an indicator plot for the development of a blight epiphytotic on a potato farm at Armstrong, Iowa, 60 miles northwest of Crystal Lake. The pathogen developed at the same pace at both locations although blight was first discovered at Armstrong in the same stage as at Crystal Lake.

In 1949, the data from weather instruments distributed at three locations in northern Iowa demonstrated that differences in rainfall, temperature, and relative humidity occur within relatively short distances. However, the temperature and relative humidity pattern was the same for all locations.

Therefore, local weather conditions may or may not favor the late blight pathogen while conditions in another locality of the same region may be unfavorable. The distribution of weather instruments in fields at several localities provides a more representative sample of the conditions within a given area.

The results of this investigation indicate that with a weekly frequency of six or more hours of favorable atmospheric humidity and temperature, providing the daily maximum temperatures remain well below 90° F., cyclic sporulation and secondary infection of the pathogen will occur as long as there is living tissue to support reinfection. Secondary infection seemed to occur in five-day to weekly cycles as shown by the results at Crystal Lake and Clear Lake.

At Crystal Lake and Clear Lake, there were occasional days between infection cycles when conditions were unfavorable. However, every fifth or seventh day conditions were favorable for sporulation, spore germination and infection.

At Clear Lake the extensity of blight very nearly doubled every seven days. This fact indicated that at weekly intervals the pathogen had favorable conditions for sporulation and subsequent spore germination. Hygrothermograph records substantiated the occurrence of favorable conditions. These results suggest that forecasts might be developed from weekly temperature-humidity hygrothermograph records obtained from potato fields.

SUMMARY

Mineral and peat potato plantings within 2000 feet of one another were sprayed with sporangia of P. infestans at the same time. Late blight appeared within seven days in the peat potatoes, but not in the plants on the mineral soil. At the end of three weeks, 100 percent of the potato plants in the peat plot were diseased while none of the plants in the mineral soil were

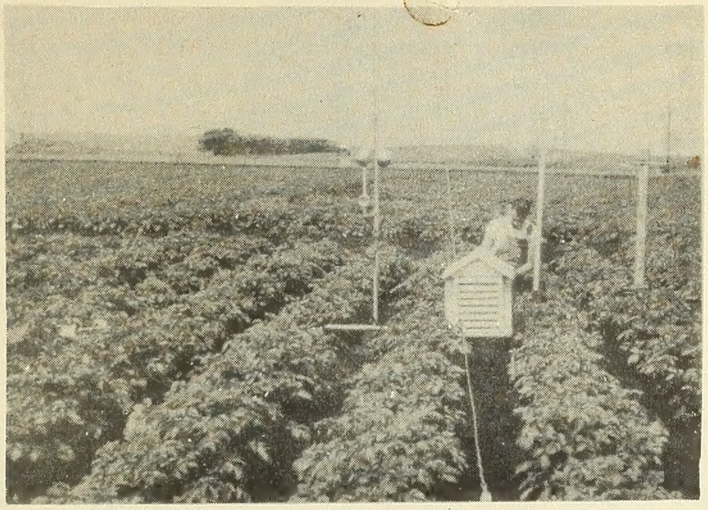

Figure 13. PEAT PLOT, CRYSTAL LAKE, IOWA, AT TIME OF INOCULATION, JUNE 21, 1948. NOTE WEATHER RECORDING INSTRUMENTS.

infected.

Temperature and humidity data obtained on both plots after inoculation were analyzed for an explanation of the above phenomenon. On the average, slightly higher temperatures (less than 1.4° F.) and lower humidities prevailed on the mineral plot especially at the lower levels in the potato foliage. However, the above factors alone did not explain the failure of P. infestans to develop on the plants in the mineral plot. The growth of the plants was better on the peat than on the mineral soil. There was more foliage on the former than on the latter.

On both plots the temperature was slightly higher in the foliage during the daytime and slightly lower at night. In comparing temperatures recorded over bare ground and potato cover only slight differences were noted at the various heights. However, over bare ground the temperature trend was the same as over potato cover. The lower levels were cooler at night and warmer in the day.

Humidity was always slightly lower at five feet above ground than at one-half or 15 inches above ground. However, the differences were less than a degree depression of the wet-bulb thermometer.

Comparisons of temperature data for 22 days from the Crystal Lake potato plot on peat soil with similar data from Britt and Forest City, revealed that generally the temperature in the potato plot was lower than that at the Weather Bureau stations. This suggests that Weather Bureau station average temperature data can be misleading in some instances.

At Clear Lake successful initiation of late blight occurred when temperatures were 75° F. or less each day for eight days and the relative humidity was 90% or more for 10 hours each day. These favorable conditions occurred frequently during sporulation and therefore promoted secondary infection continuously throughout the season. Five weeks after initial sporulation 100 percent of the plants were infected.

In the disease plot apparently healthy leaves were picked at 3, 6, and 9 AM and 12 Noon and incubated. Late blight lesions appeared on some leaves from each collection, indicating that viable sporangia may have been adrift until noon. More bottom than top leaves became infected, suggesting that the sporangia remained viable longer among the lower shaded leaves.

The studies in north-central Iowa, involving Crystal Lake and Clear Lake representing two counties, suggest that temperature and humidity records from an inoculated plot afford data that will permit predicting the rate of spread of the late blight fungus once primary infection has been initiated in a field.

At Bedford, Indiana, P. infestans was initiated on potatoes. Within two weeks after the plants were inoculated the pathogen was killed by the continuation of 80° F. or above during the daytime.

At the Bedford, Indiana plot only minor differences were noted in temperature and humidity at five-foot intervals above the soil. However, there were wide fluctuations in temperature and humidity between days, and at various times during a 24 hour period.

IOWA AGRICULTURAL EXPERIMENT STATION, INDIANA AGRICULTURAL EXPERIMENT STATION, AND CROP PLANT DISEASE FORECASTING PROJECT, PLANT DISEASE SURVEY